Swiss National
Science Foundation

Universität
Zürich$^{\text{UZH}}$

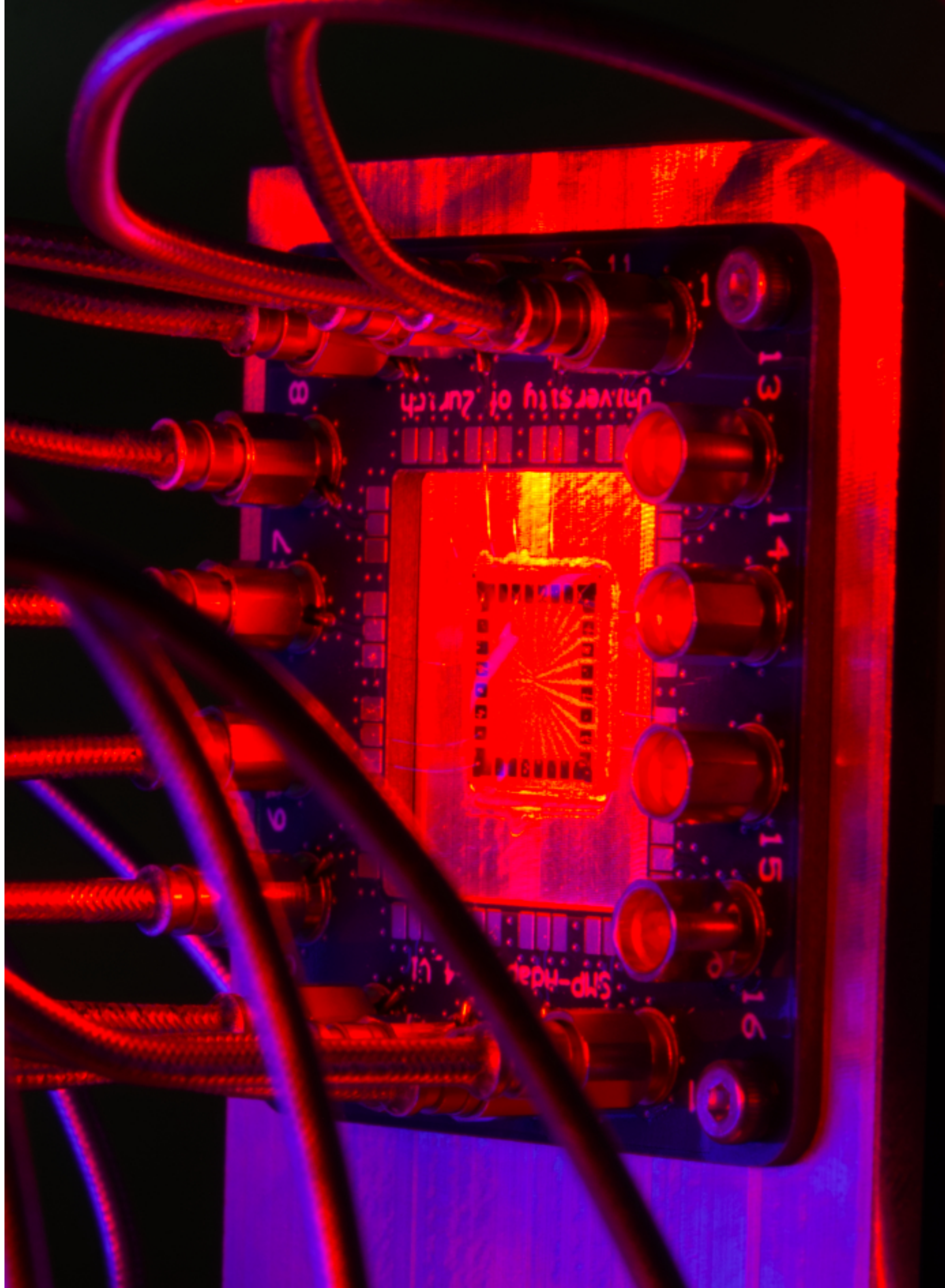
Search for DM with SNSPD: the QROCODILE experiment

Qrocodile

Chiara Capelli (University of Zurich)

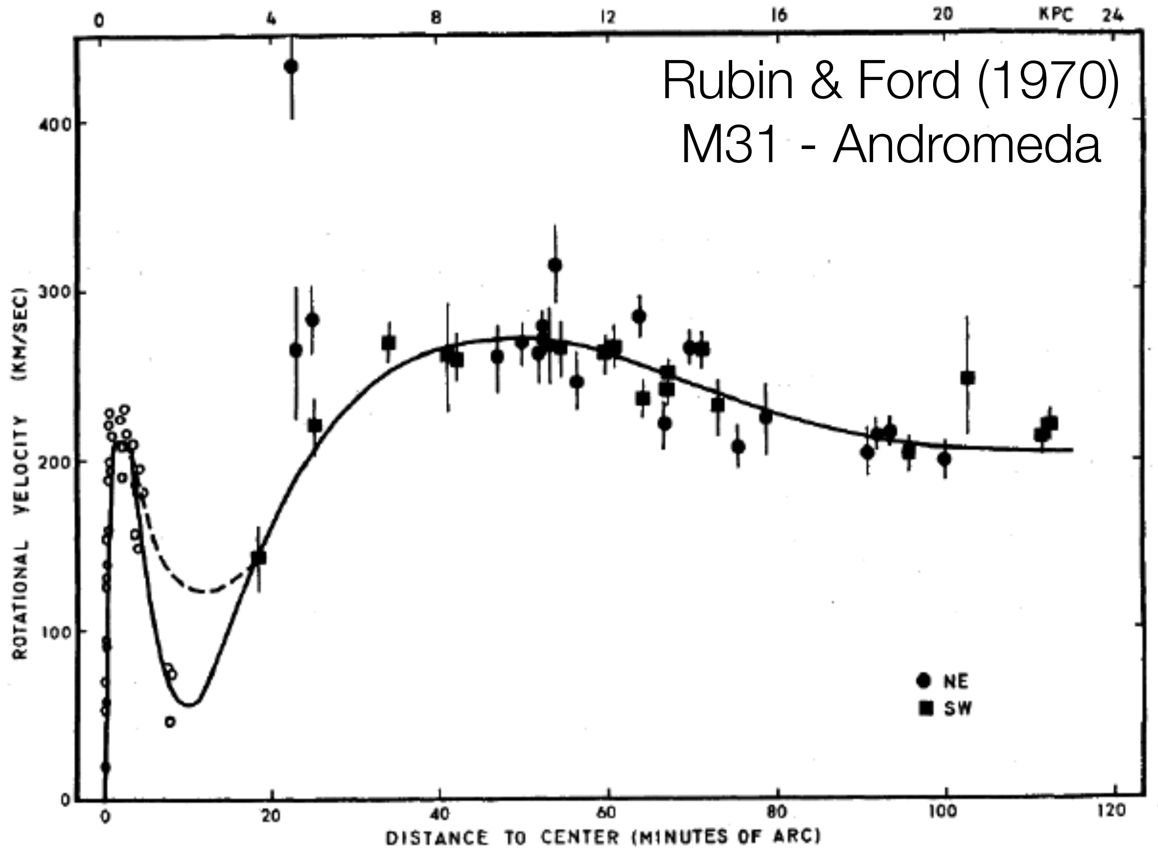
On behalf of the QROCODILE collaboration

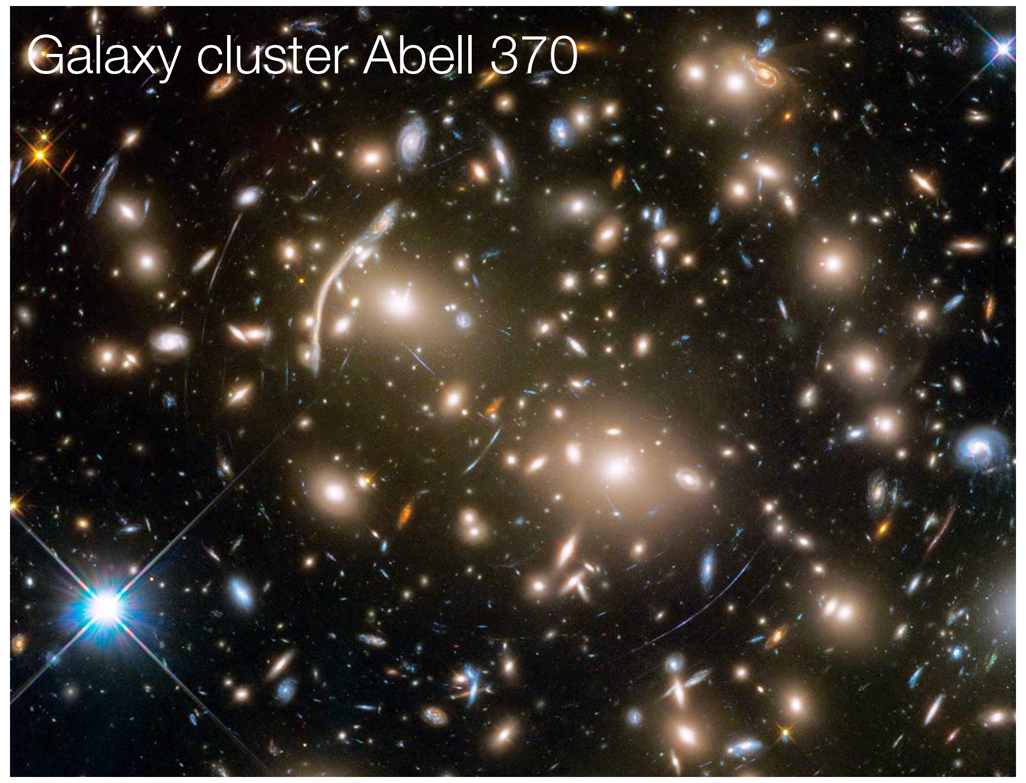
Superconducting Technologies for Dark Matter
Roma
May 11-13, 2026

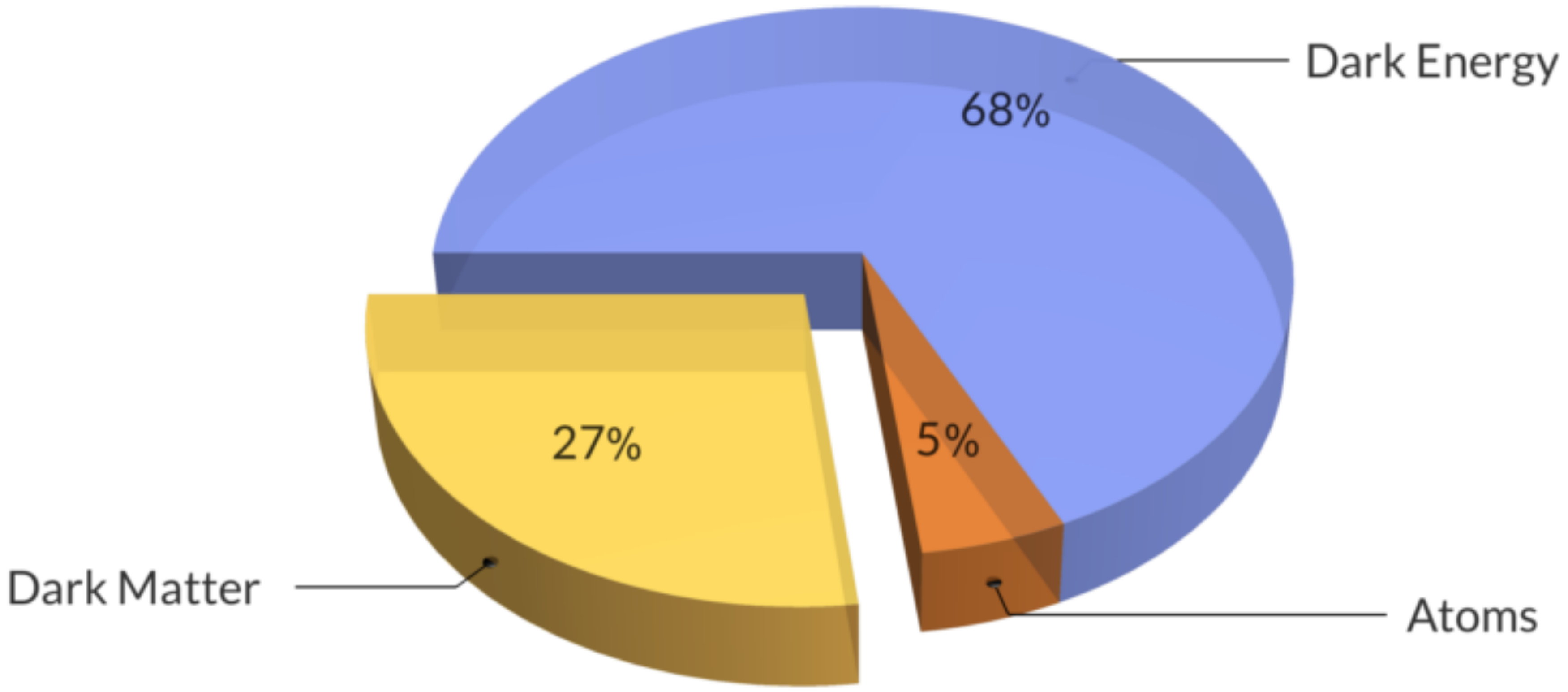


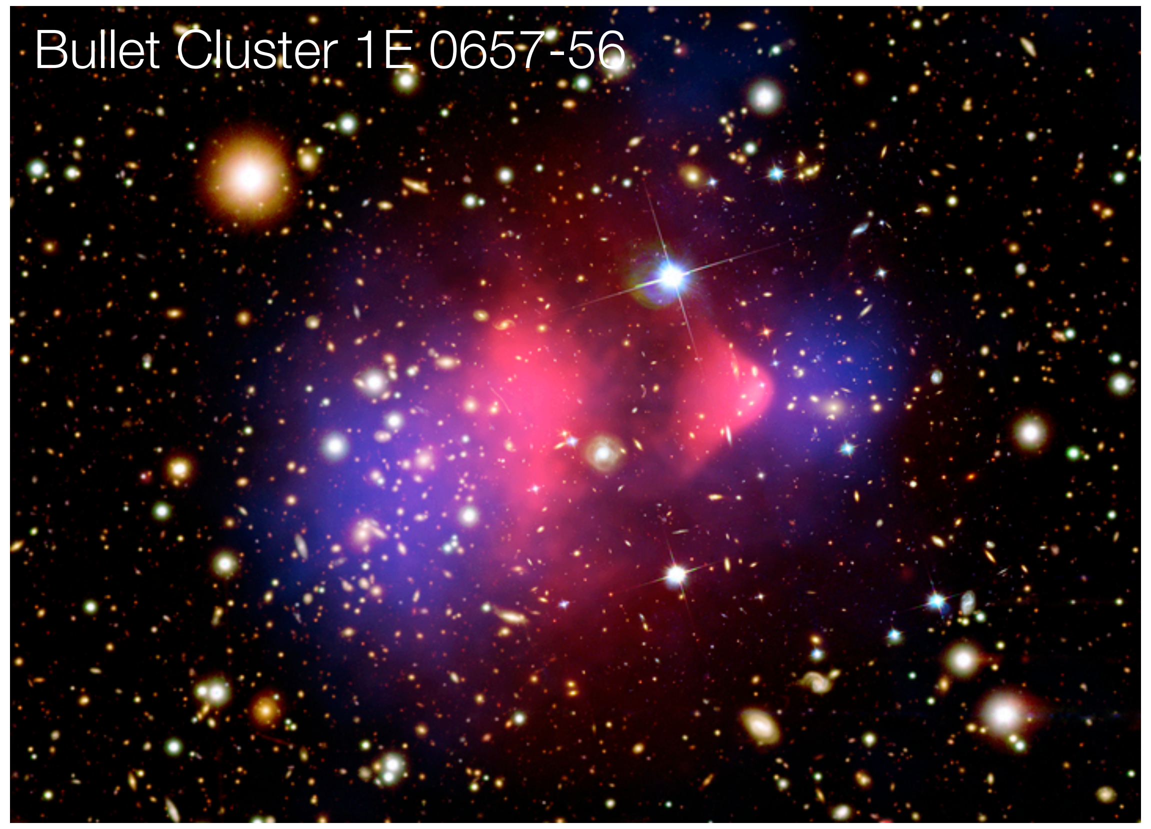
Dark matter

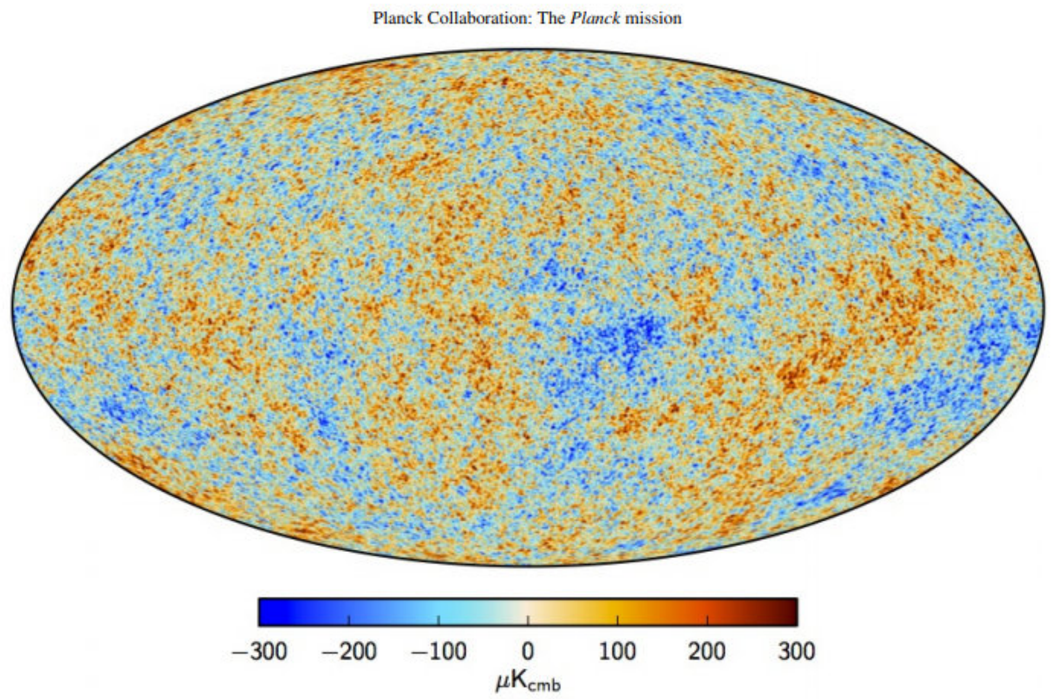
- Several cosmological observations from gravitational interaction (galaxies velocity dispersion, star rotation curves, gravitational lensing, galaxy clusters, CMB)





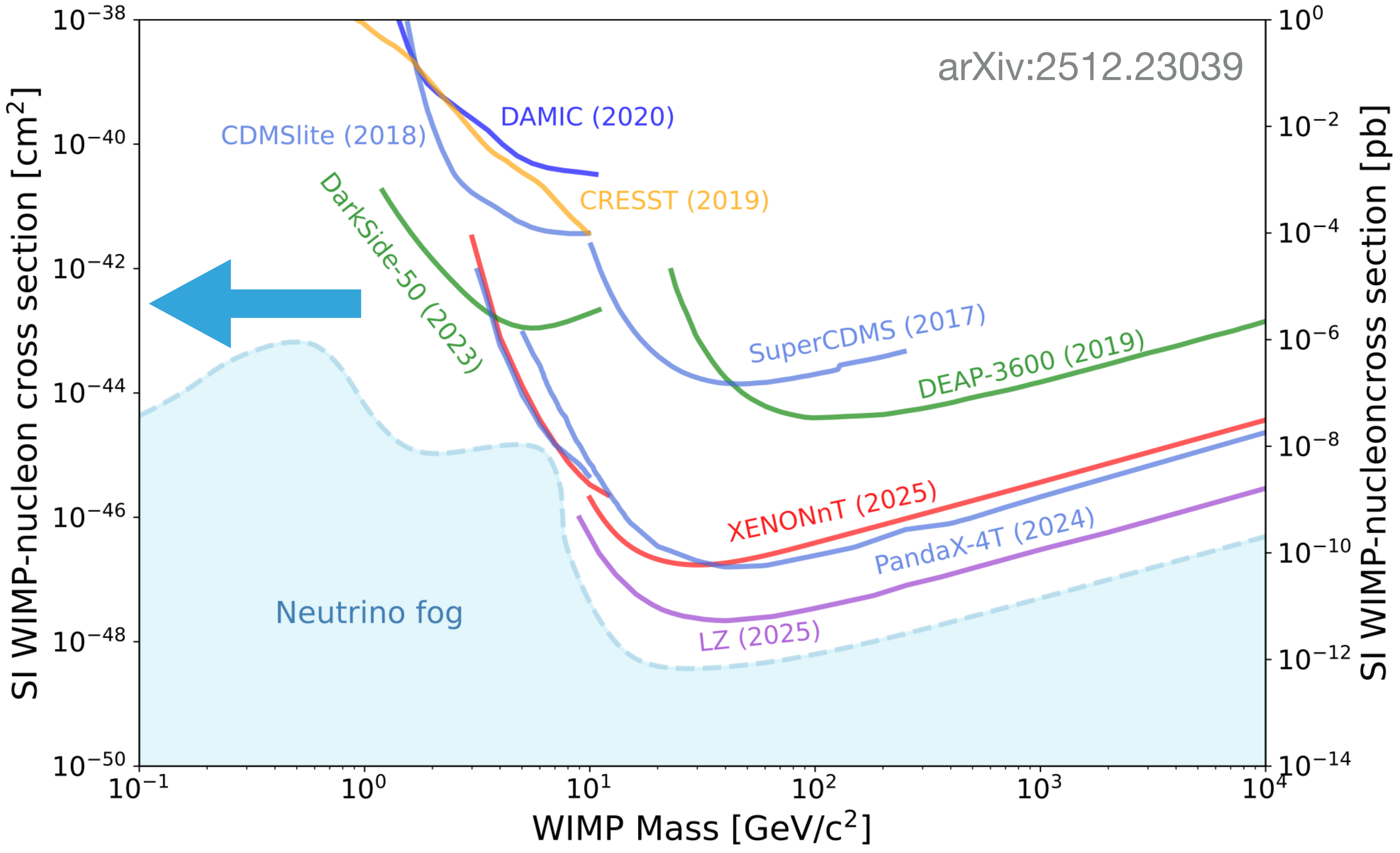






- DM constitutes ~84% of the matter in the Universe
- Non baryonic
- Non relativistic (cold)
- Electrically neutral
- Neither absorbing nor emitting light

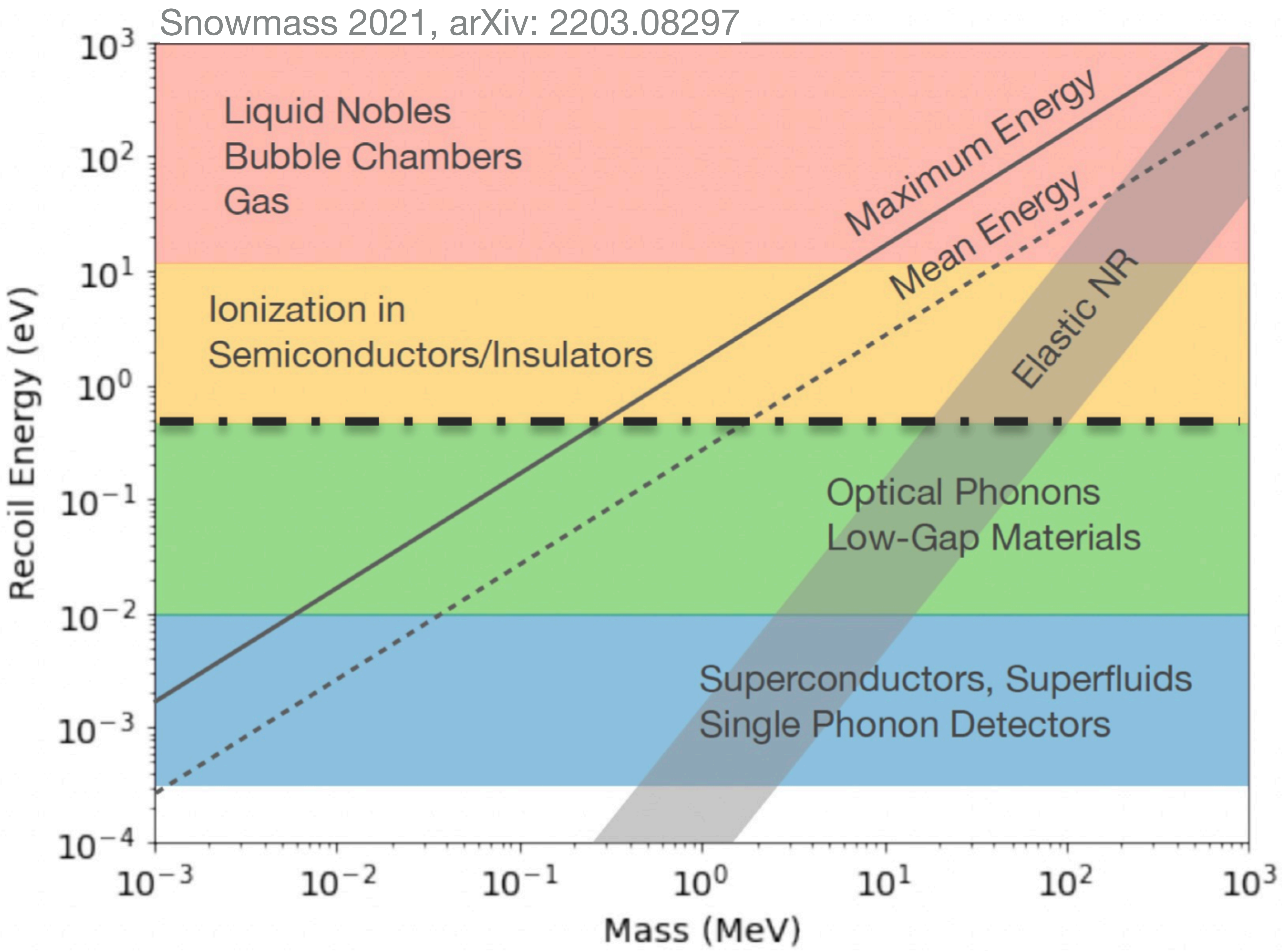
Low mass DM scenario


arXiv:2512.23039

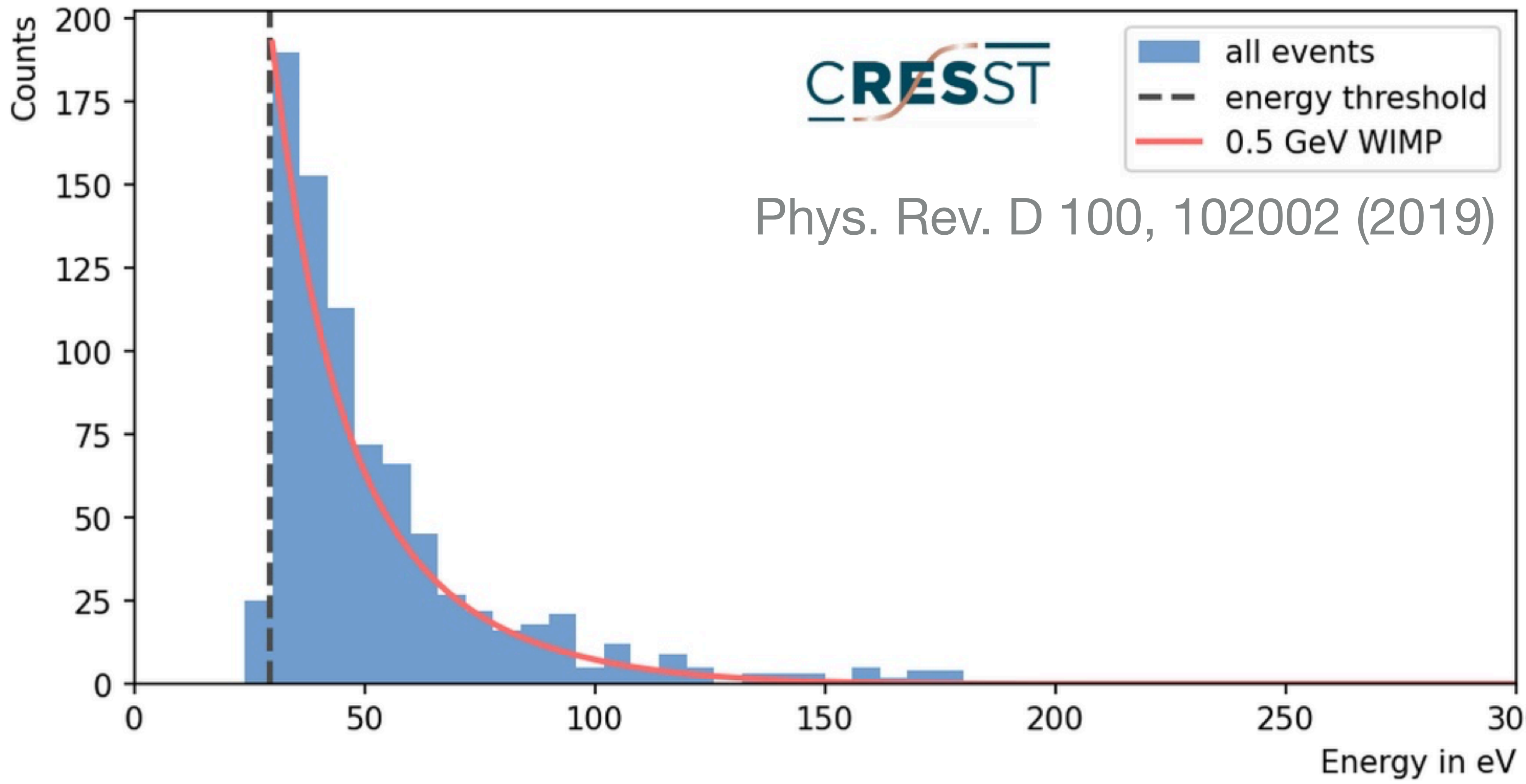
- Development of new technologies required to explore lower masses
- For sub-MeV masses needed sub-eV threshold

Max. Energy for DM moving at escape velocity ~544 km/s

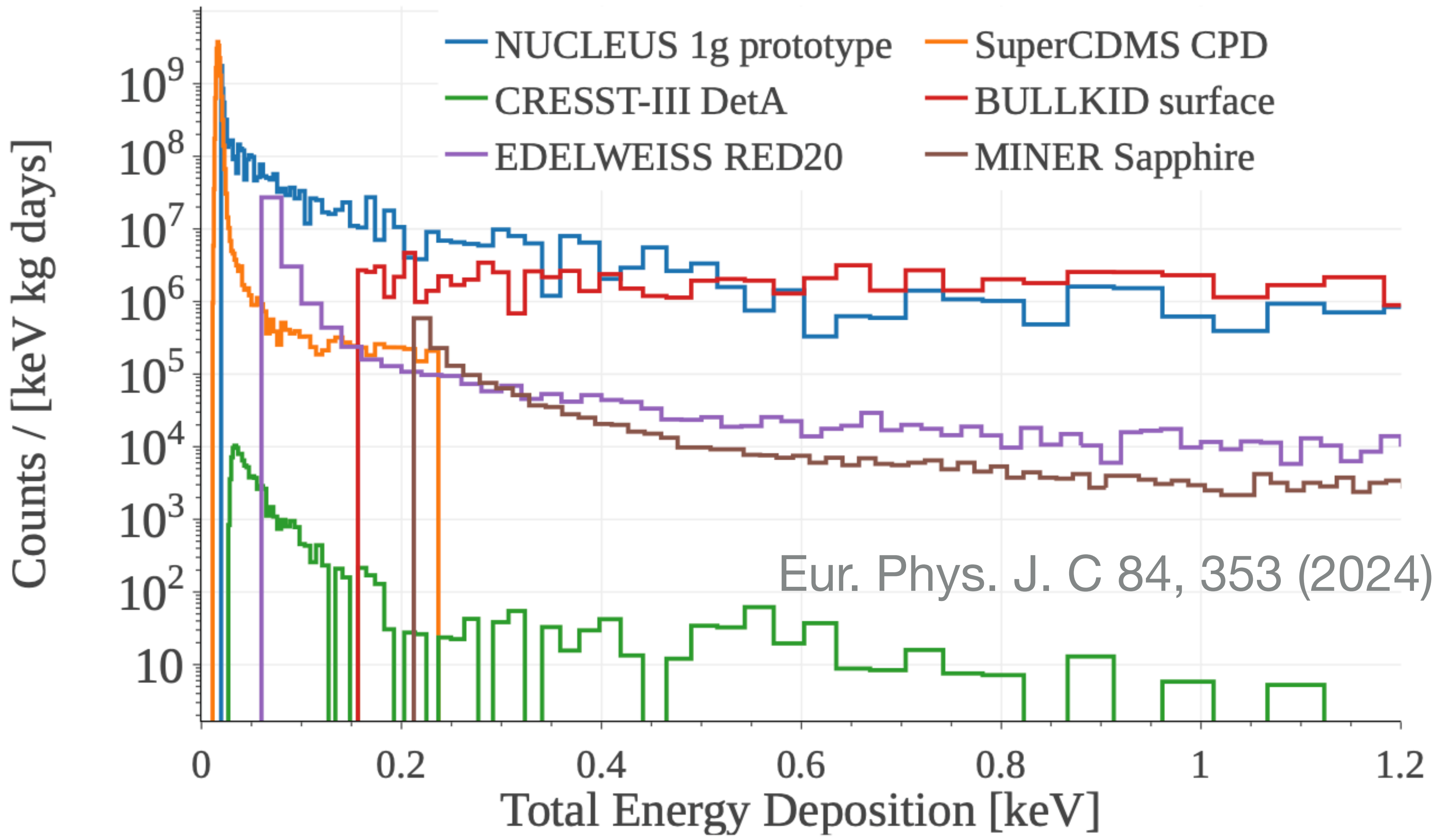
Mean energy for DM moving at mean velocity ~220 km/s


Snowmass 2021, arXiv: 2203.08297

Low energy excess (LEE)



Phys. Rev. D 100, 102002 (2019)



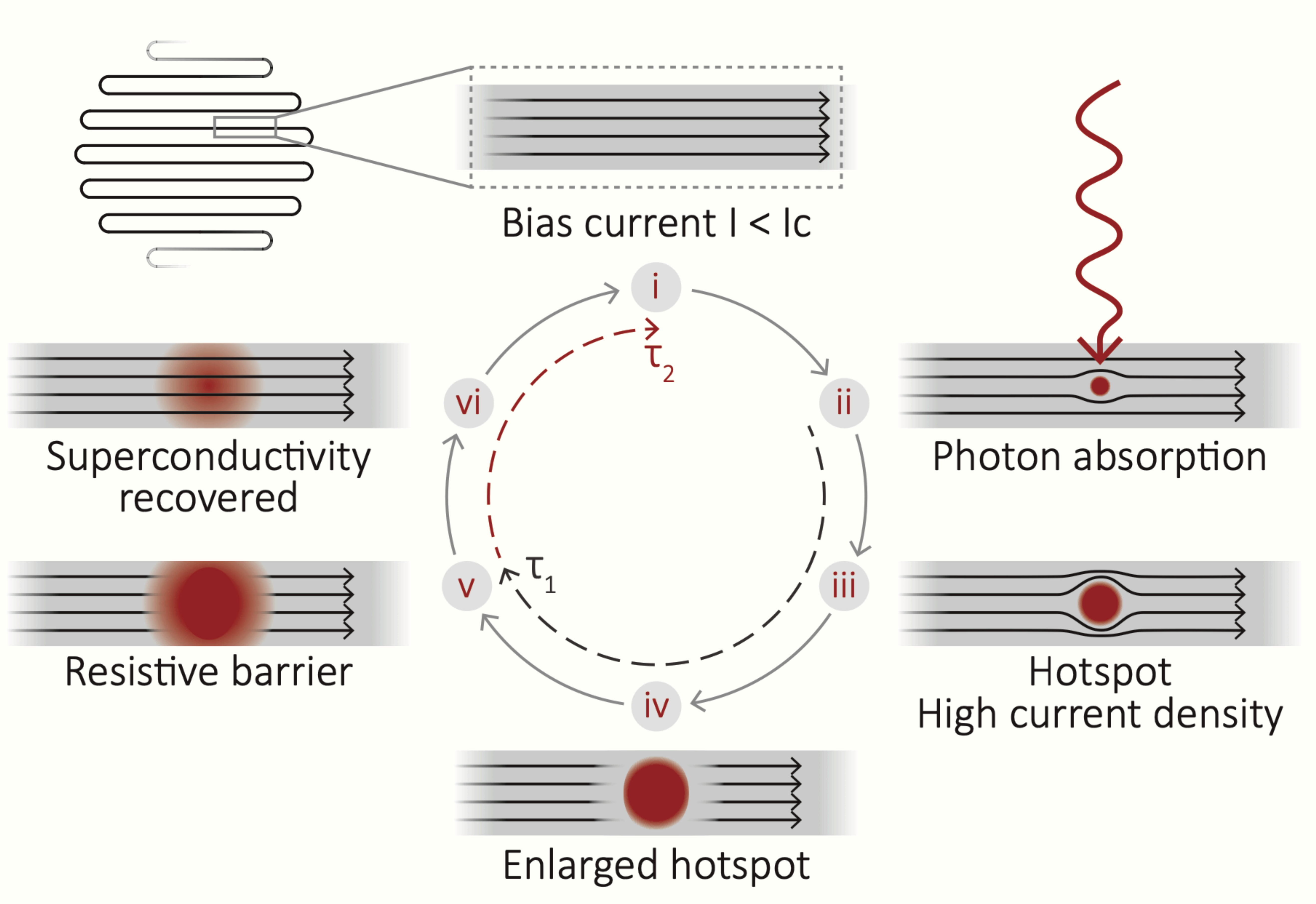
Eur. Phys. J. C 84, 353 (2024)

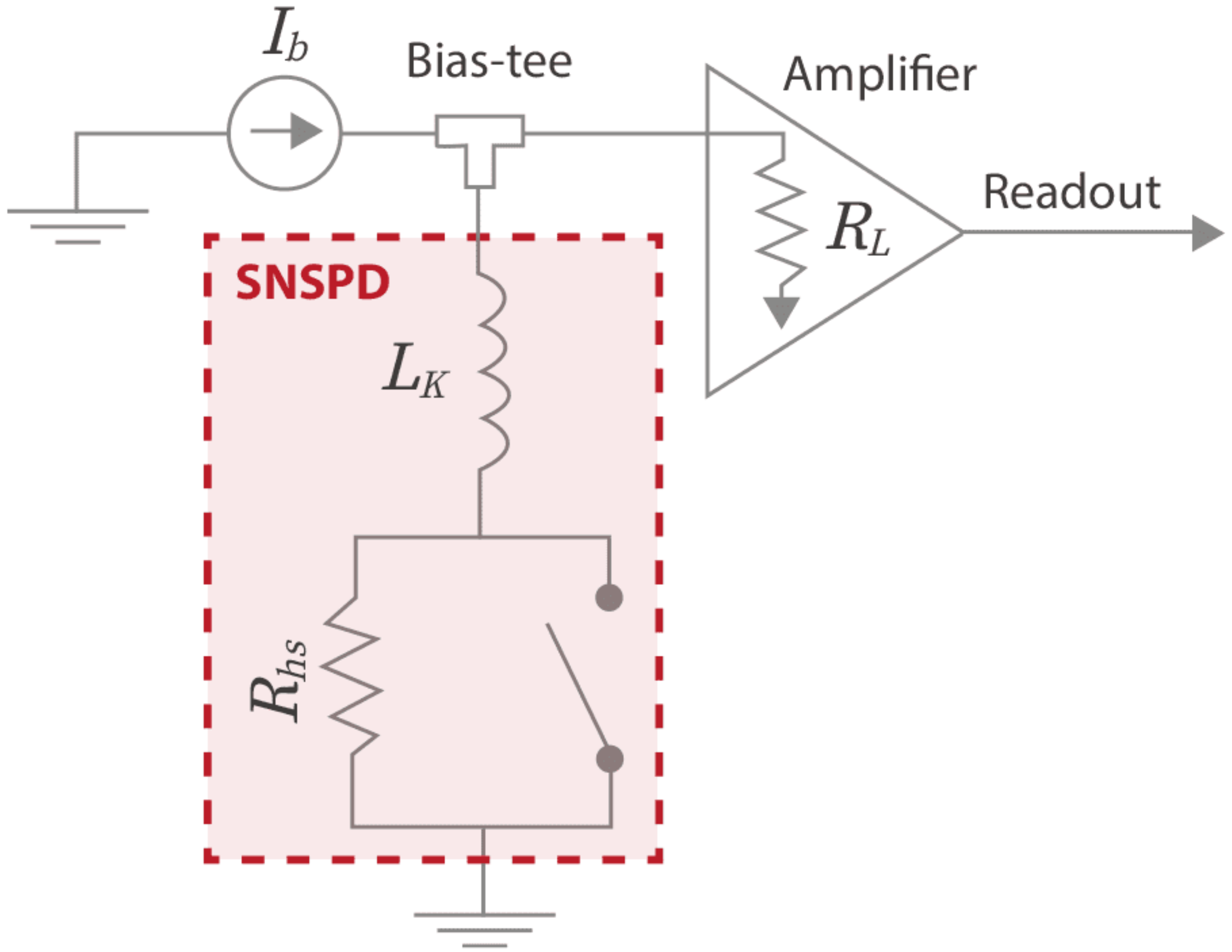
- Low energy excess not understood
- Shape similar to light DM or CEvNS → limit sensitivity of current experiments
- LEE not affected by charge amplification, decreases over time and it is reactivated with thermal cycles

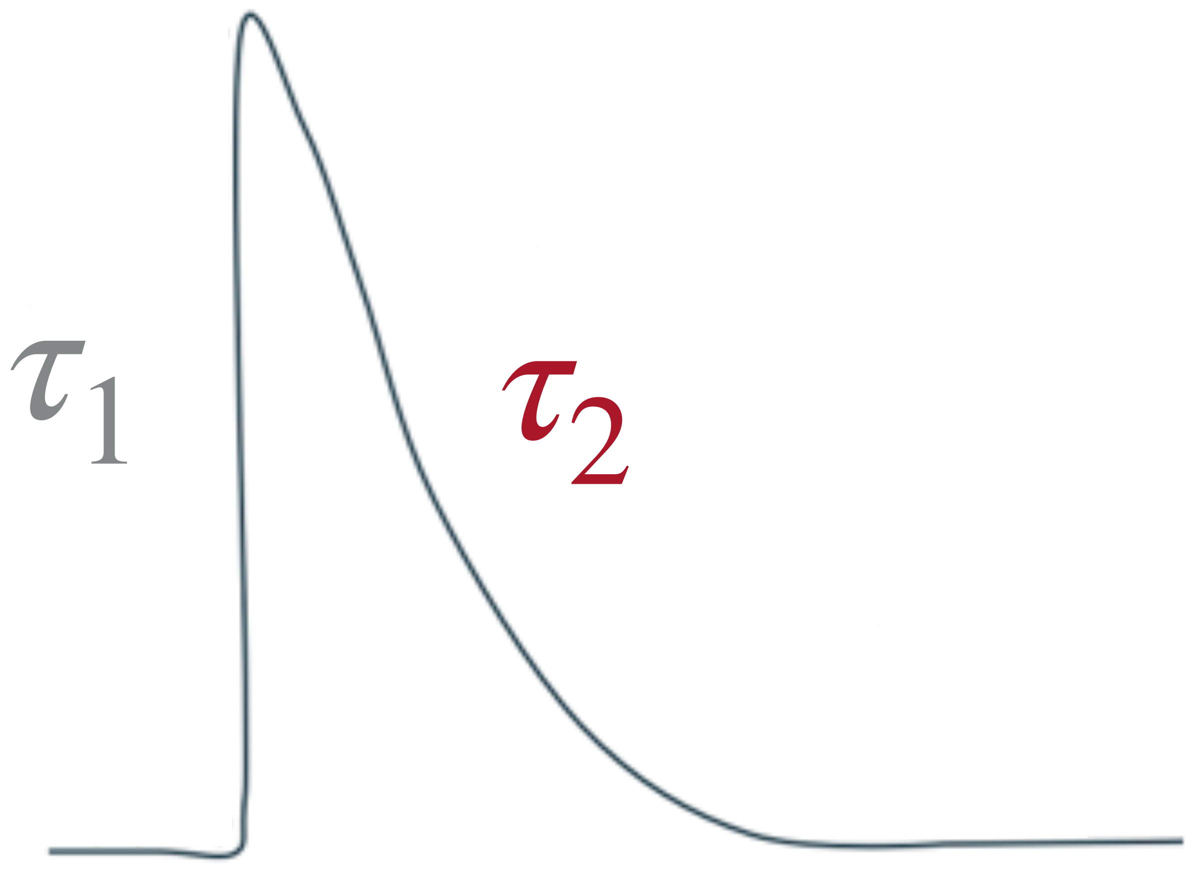
➡ Most probably due to solid state effects:
  - Stress induced by holding structures
  - Relaxation in crystal bulk
  - Events in sensor or sensor interface

SNSPD working principle

Superconducting Nanowire Single-Photon Detectors





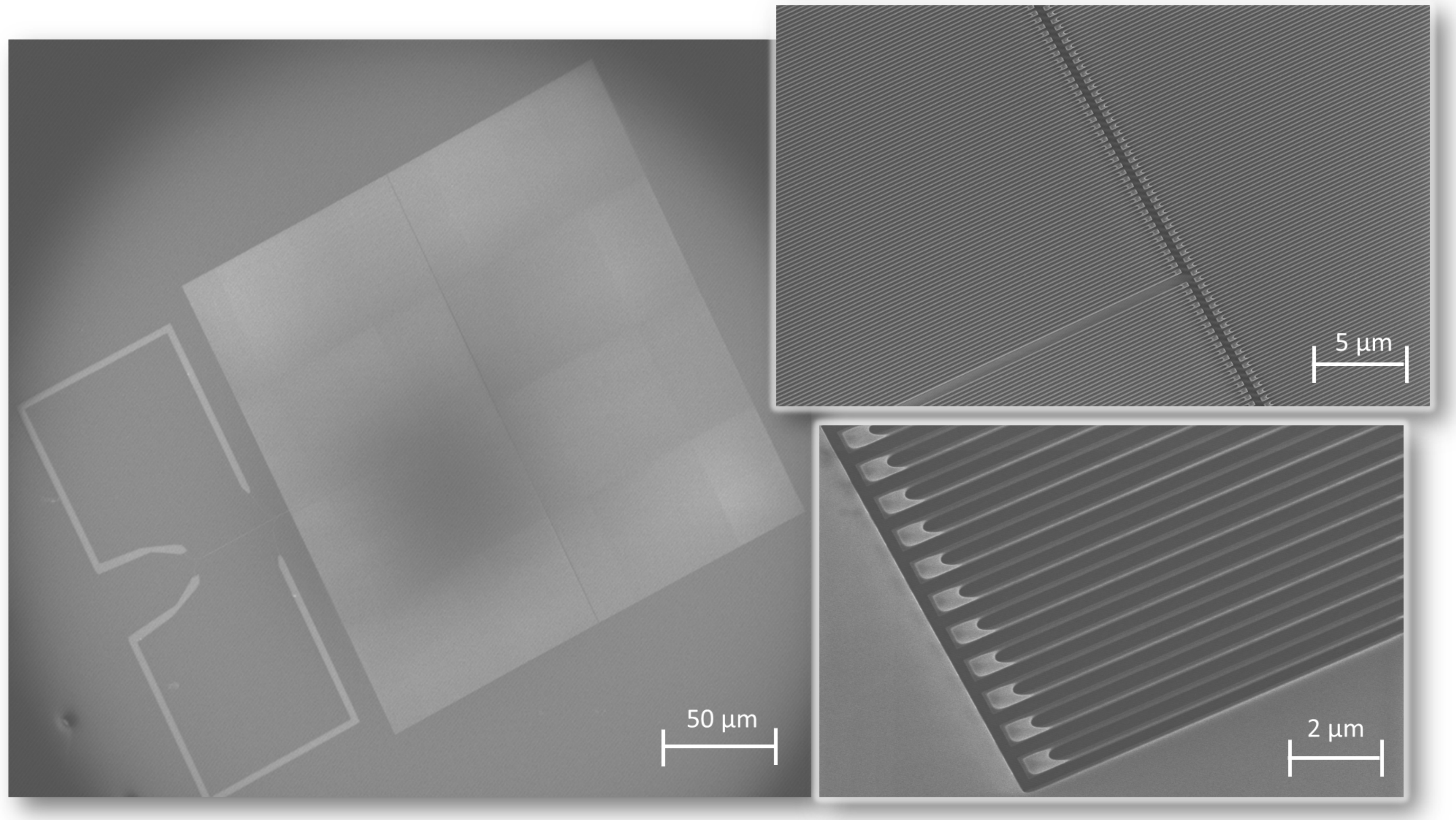


https://www.singlequantum.com/technology/
https://www.idquantique.com/quantum-detection-systems/snspd-technology/

SNSPDs

Superconducting Nanowire Single-Photon Detectors

- High detection efficiency (>90%)
- Low dark count rates
- Picosecond timing resolution



- WSi, MoSi: lower-gap materials → more quasiparticles per absorbed photon but with slower diffusion and recovery times - used for IR region
- NbN, NbTiN: higher-gap materials → respond faster but with less intrinsic energy spread

2001	2005	2011	2015	2017-2020	2020s
First developed	First operational prototype	Achieved high efficiency	Telecommunication applications	Mid-IR range	Dark matter applications

SNSPDs

Credits to Boris Korzh

Timing jitter	Intrinsic photon number resolution	Efficiency	Array size	Maximum count rate	Dark count rate	Active area	Cut-off wavelength	
18 ps	None	93%	64	1 Gcps	4 /s/mm^2	0.001 cm^2	5 µm	Records in 2016
[1] **2.6 ps**	**3-5 photons**	[2] **98%**	[3] **4x10^5**	[4,5] **1.5 Gcps**	[6] **4x10^{-5} /s/mm^2**	[3] **0.1 cm^2**	[7] **29 µm**	**Current records for isolated devices**
1 ps	**10**	**99 %**	**10^7**	**10 Gcps**	**1x10^{-6} /s/mm^2**	**1 cm^2**	**100 µm**	Expected performance by 2030

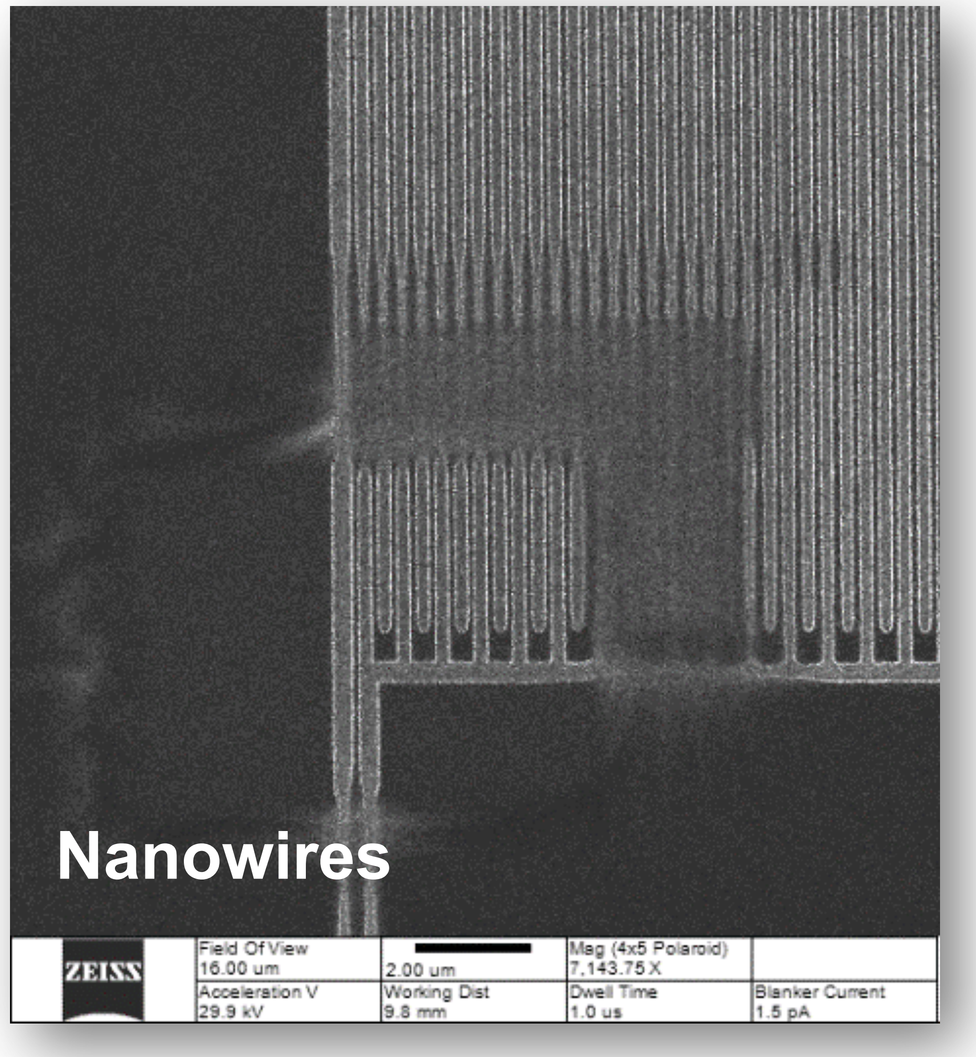
[1] Korzh, Zhao et al, ***Nature Photonics*** 14, 250 (2020)
[2] Reddy et al, ***Optica*** 7, 1649 (2020)
[3] Oripov, Rampini, Allmaras, Shaw, Nam, Korzh, and McCaughan, ***Nature*** 622, 730 (2023)
[4] Craiciu, Korzh et al, ***Optica*** 10, 183 (2023)
[5] Resta et al, ***Nano Letters*** (2023)
[6] Chiles, ***PRL*** 128, 231802 (2022)
[7] Taylor, Walter, Korzh et al, ***Optica***, (2023)

SNSPDs for dark matter

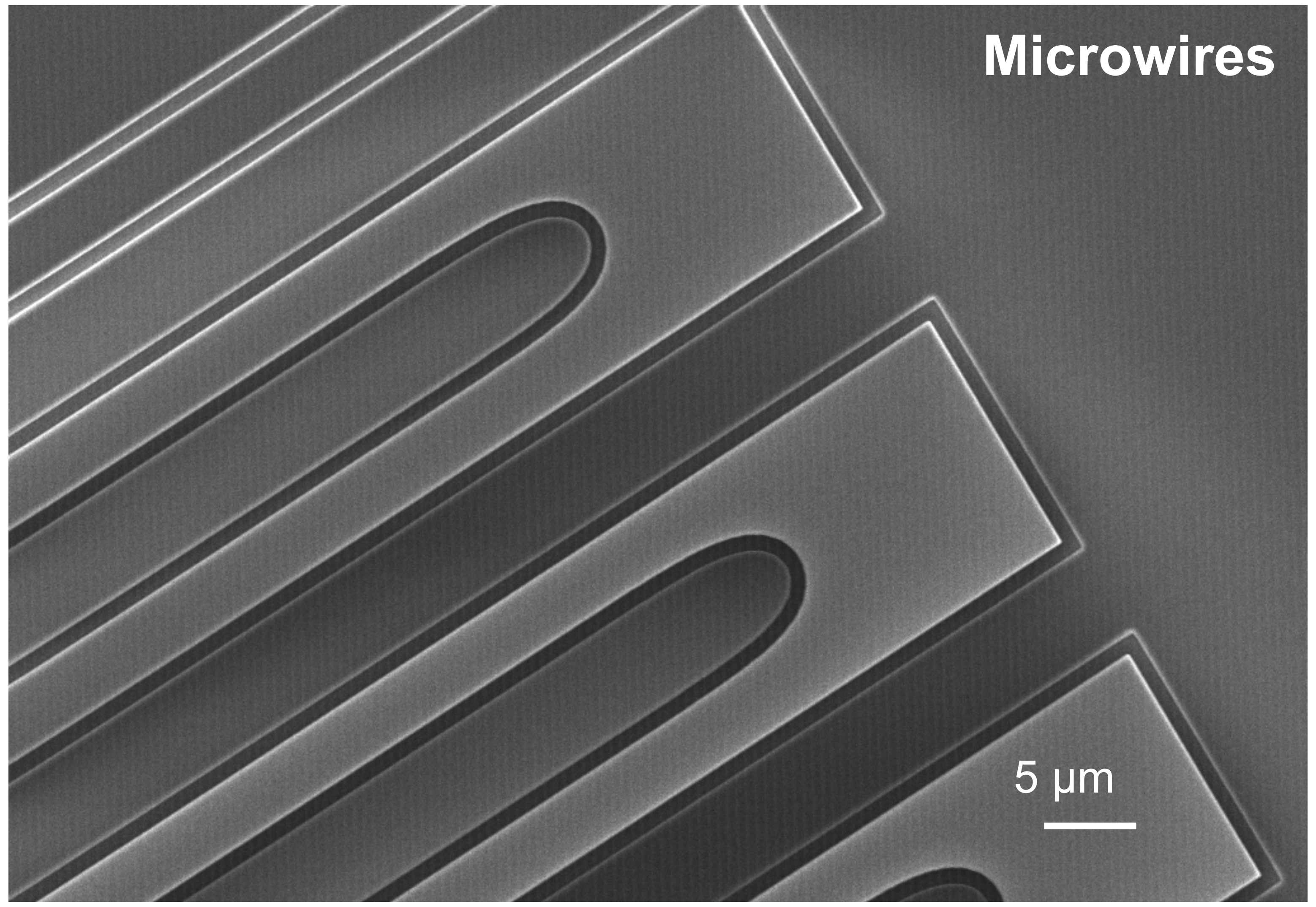
Requirements for dark matter search:

Yonit’s talk yesterday

- Large-mass detector
- Mid-infrared detection
- Low dark count rate
- Mitigation of background

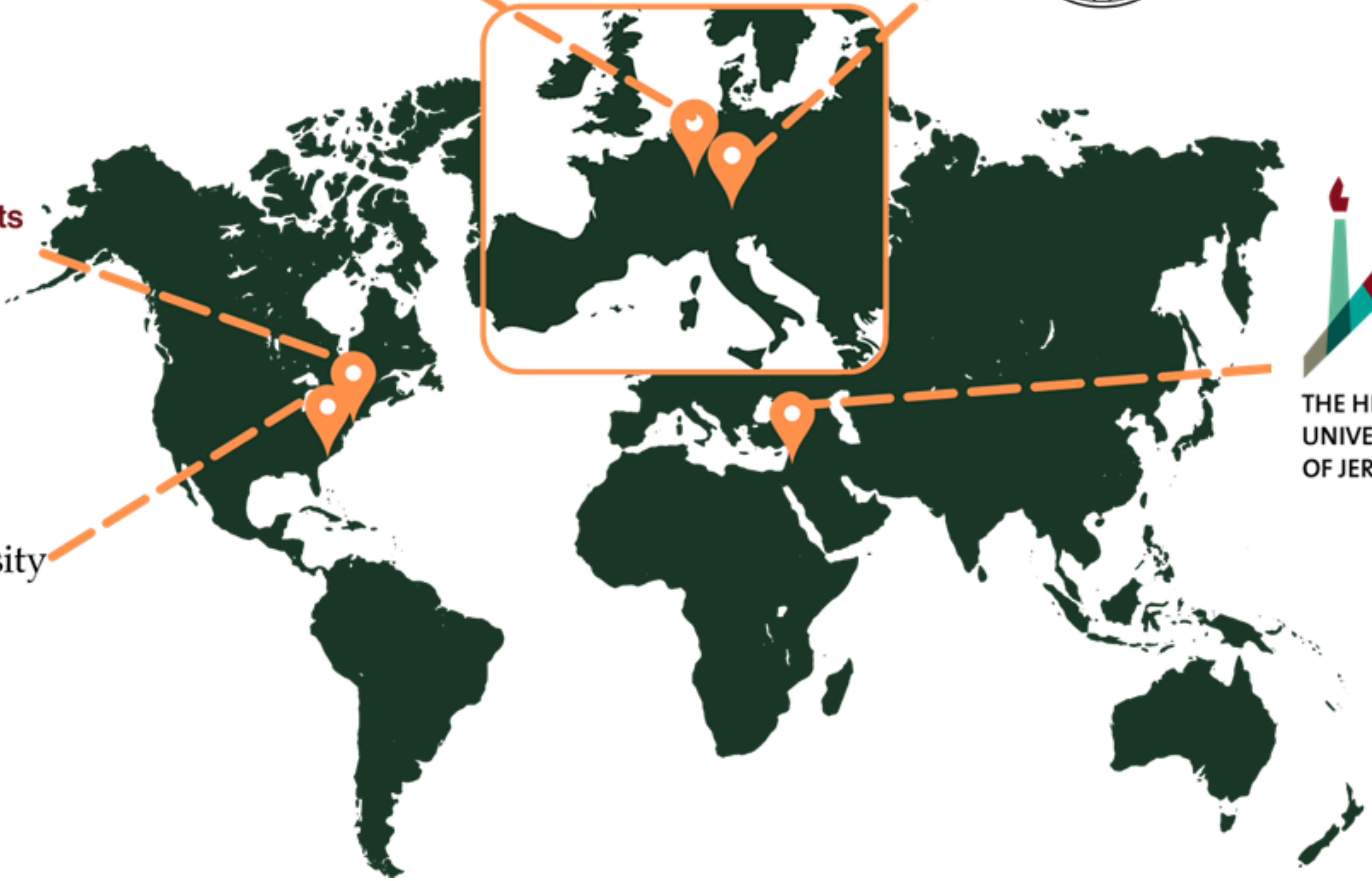


- small effective volume (active area 10x10 μm^2) → for DM microwires 1 μm wide on large area device >> 10x10 μm^2
- Complex fabrication
  - Non uniformity of wire production that affects critical current
  - Edge or internal structural defects



The QROCODILE collaboration

Quantum Resolution-Optimized Cryogenic Observatory for Dark matter Incident at Low Energy



KIT
Karlsruher Institut für Technologie

Universität Zürich UZH

Massachusetts Institute of Technology

Cornell University

THE HEBREW UNIVERSITY OF JERUSALEM

Qrocodile

https://www.qrocodile.uzh.ch

14 people from 4 countries

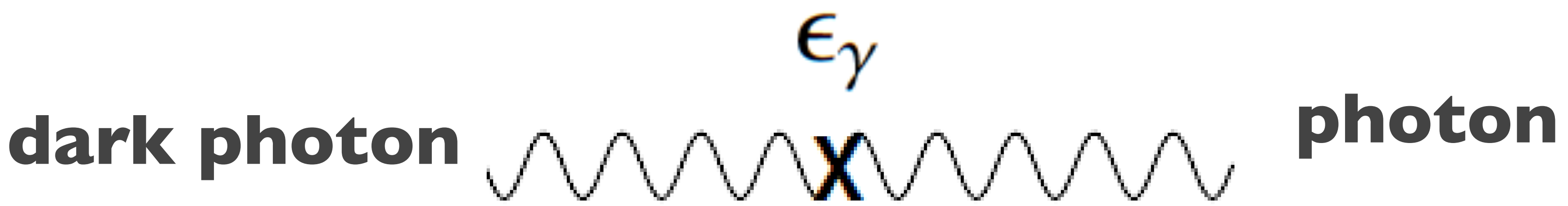
To be updated!

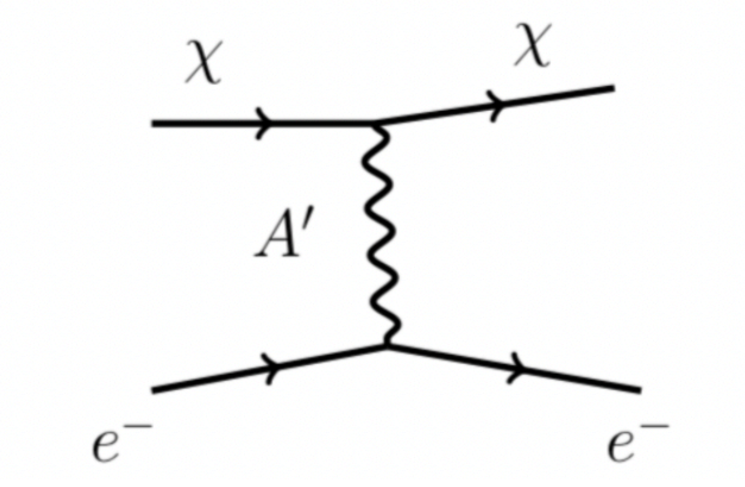
The QROCODILE experiment

Phys.Rev.Lett. 135 (2025) 8, 081002

- DM particle with mass down to 30 keV
- SNSPD as target = sensor
- Sensitive to scatter and absorption of dark matter
- Coupling between phonons and quasiparticles in the detector → interaction with electrons and nucleons
- Directionality from anisotropy in the device geometry → reject background and select DM from Galactic halo

QROCODILE @ UZH cryostat

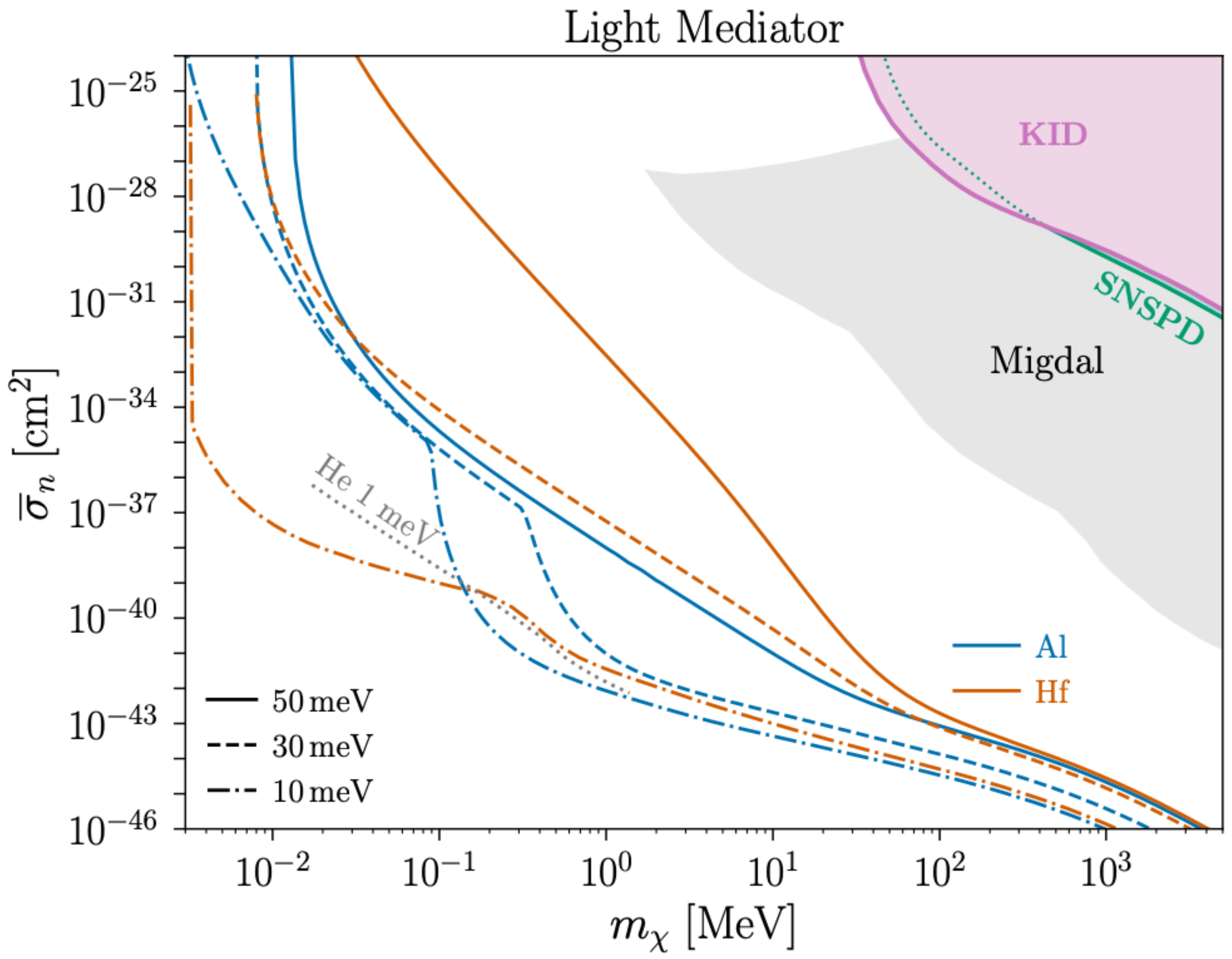


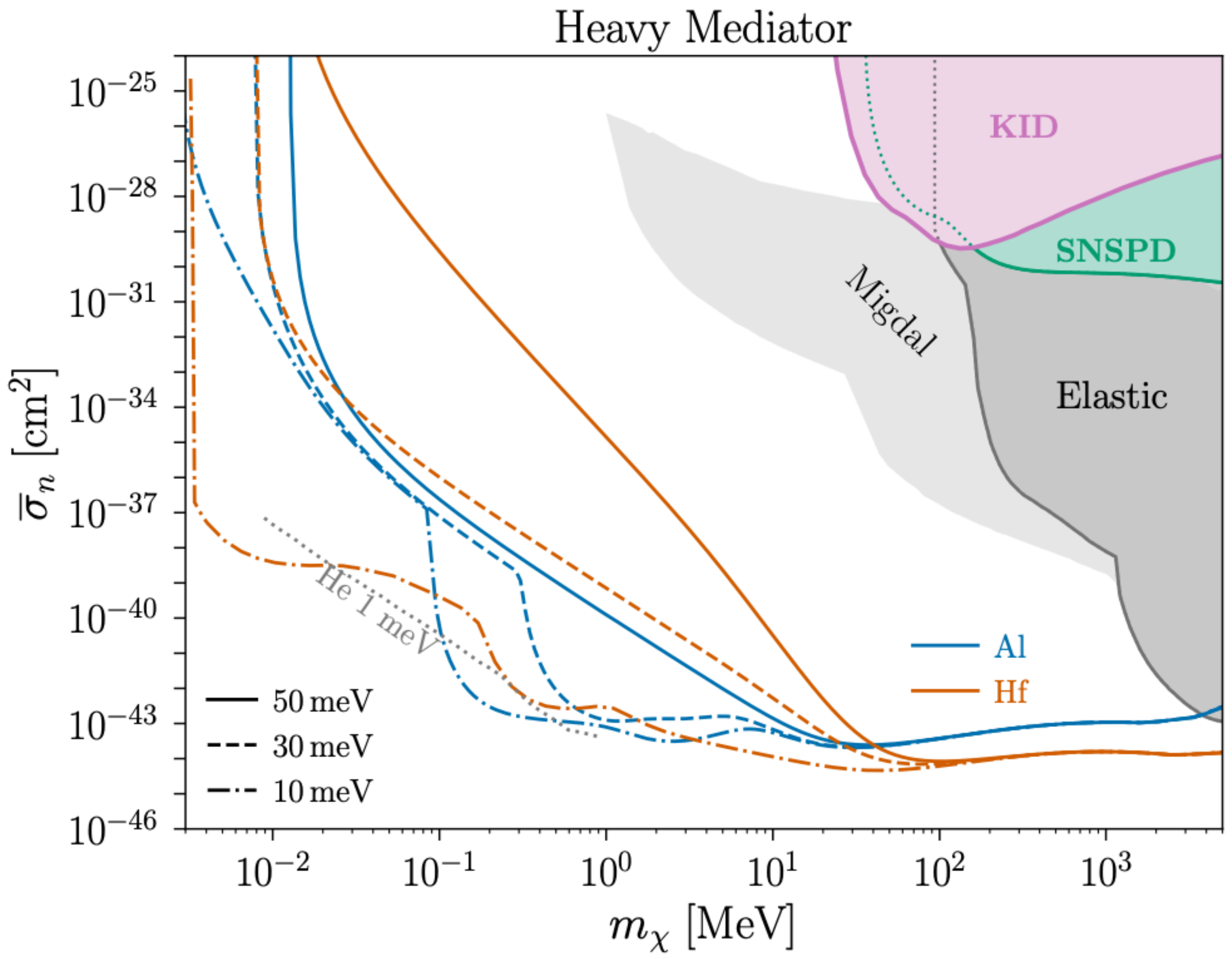


DM-nucleon scattering

arXiv: 2412.16283

- At low masses interaction dominated by many-body processes rather than elastic scattering
- SNSPD sensitive to nuclear scattering via phonon production
- Phonons break Cooper pairs and produce free quasiparticles for E > 2Δ → transition to the normal metal state
- Same detector sensitive to electronic and nuclear interaction



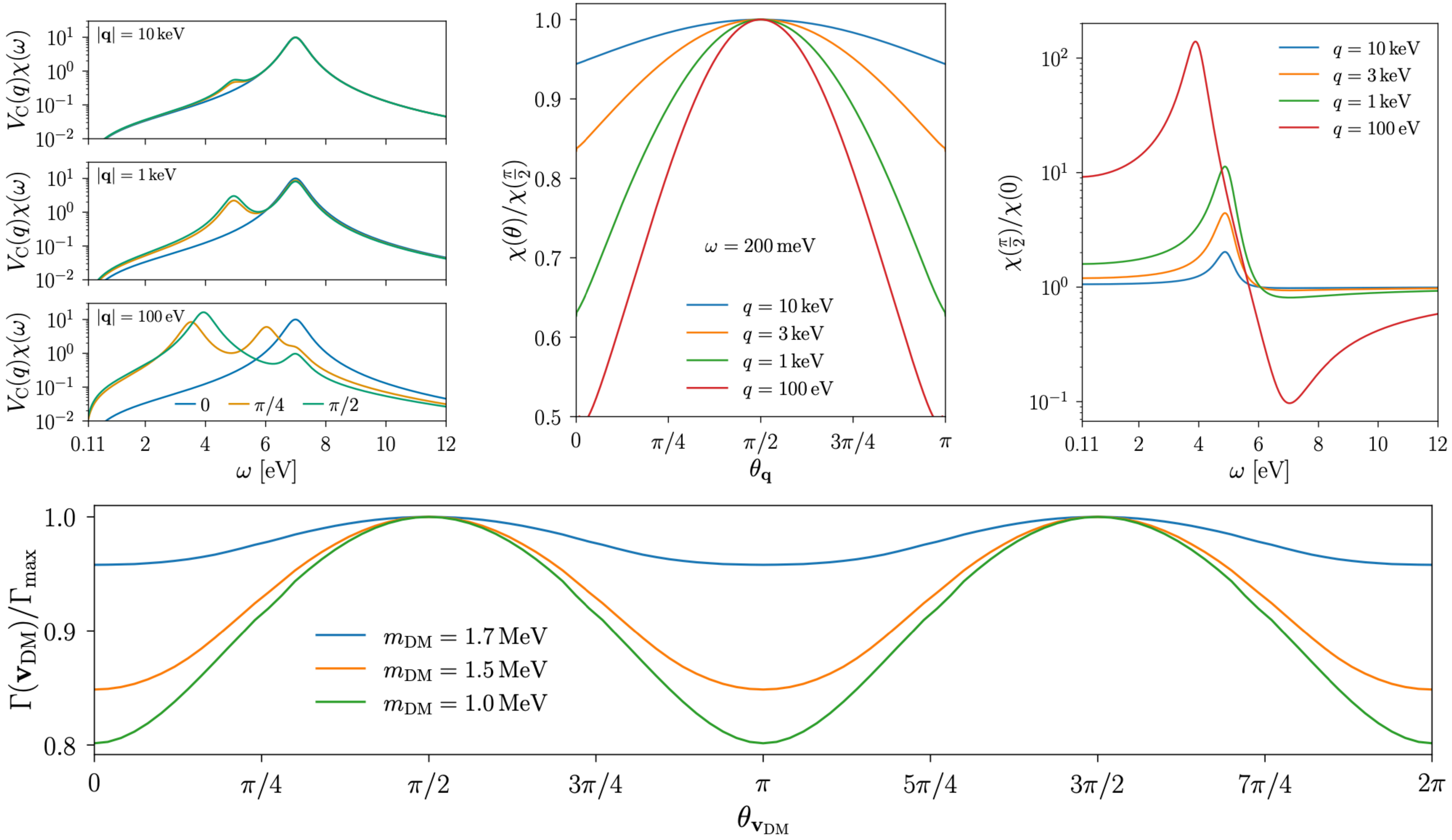


1 kg yr exposure
on existing devices

Directionality

Phys.Rev.Lett. 135 (2025) 8, 081002

- Dynamic structure factor to model response of the target material
- Calculations assuming infinite bulk volume → approximation fails for target dimensions < inverse momentum transfer → required geometric corrections

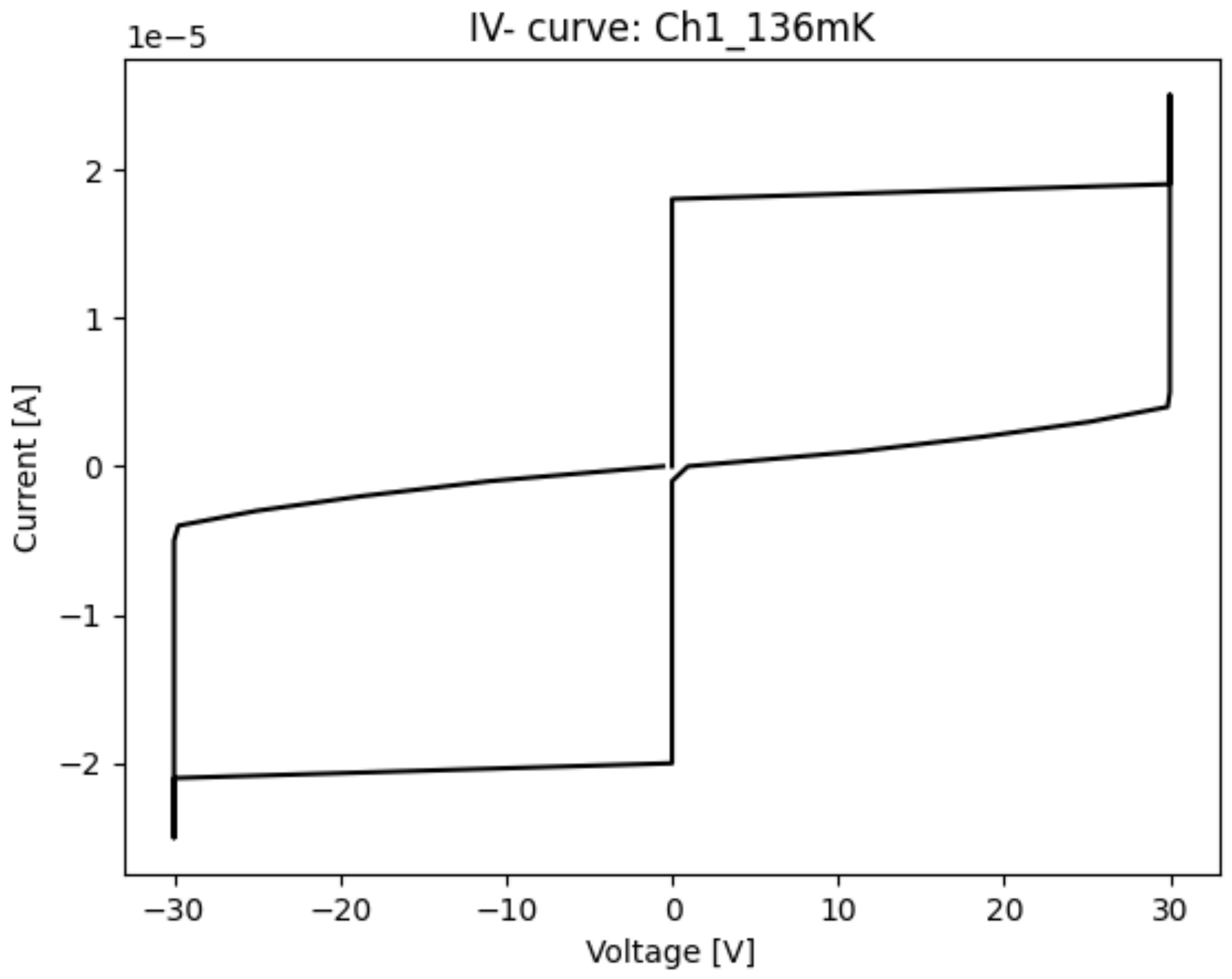


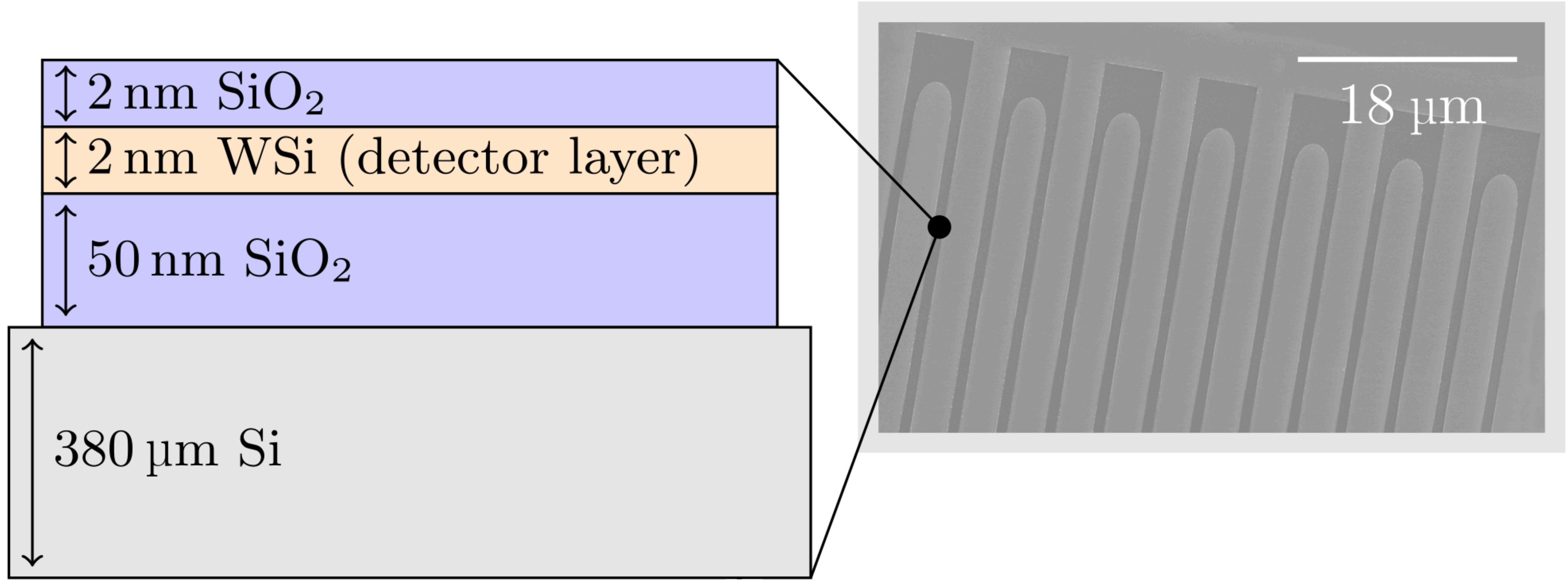
- Possible only for light masses:
  - 200 keV DM → 1/q ~ 1 nm
  - 30 keV DM → 1/q ~ 10 nm not negligible on 2 nm layer

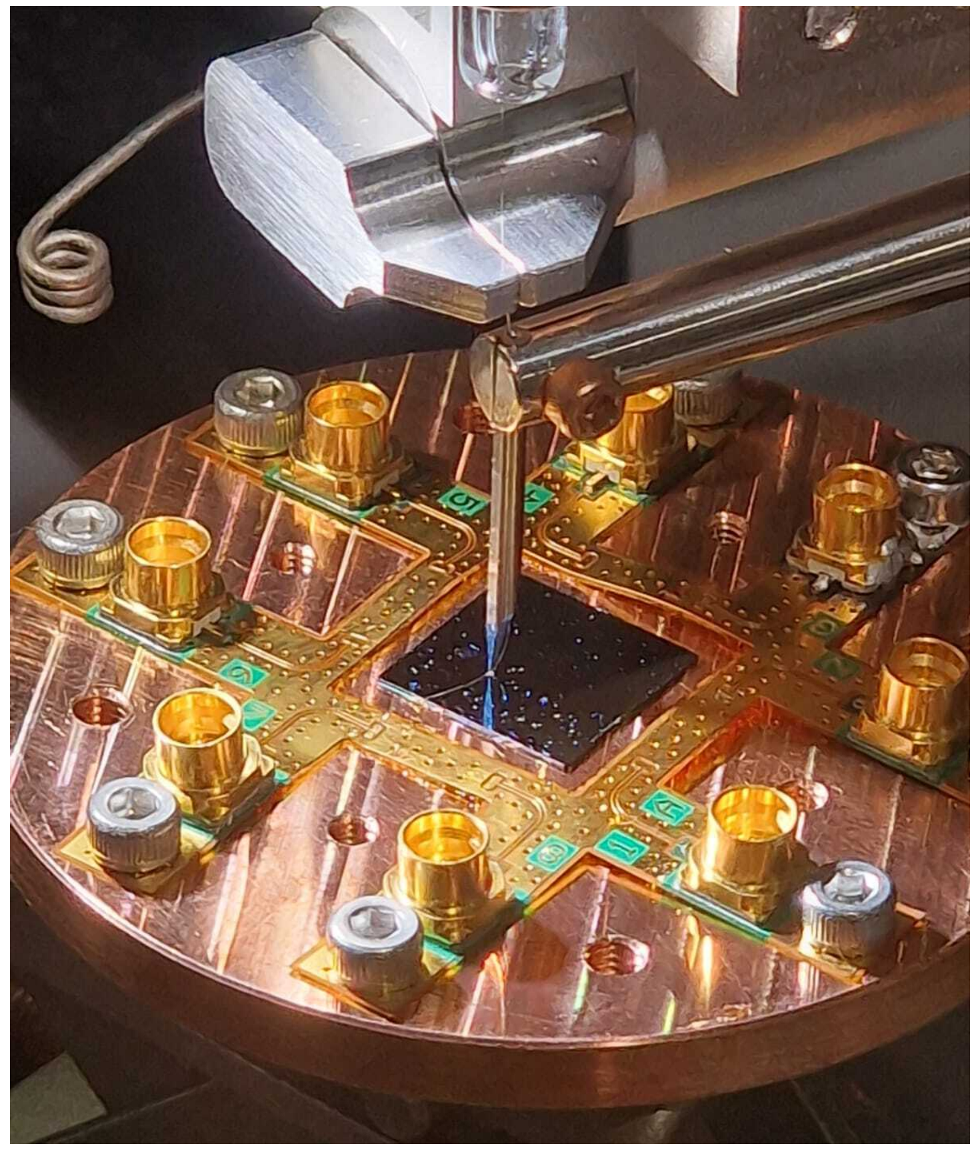
The sensor

Phys.Rev.Lett. 135 (2025) 8, 081002

- 10x10 mm^2 chip size
- 600x600 μm^2 active area with 1 μm wire width
- 25% filling factor
- WSi 45:55 superconducting layer 2 nm thick
- Transition temperature at 1.73 K
- Si/SiO$_2$ substrate







Calibration

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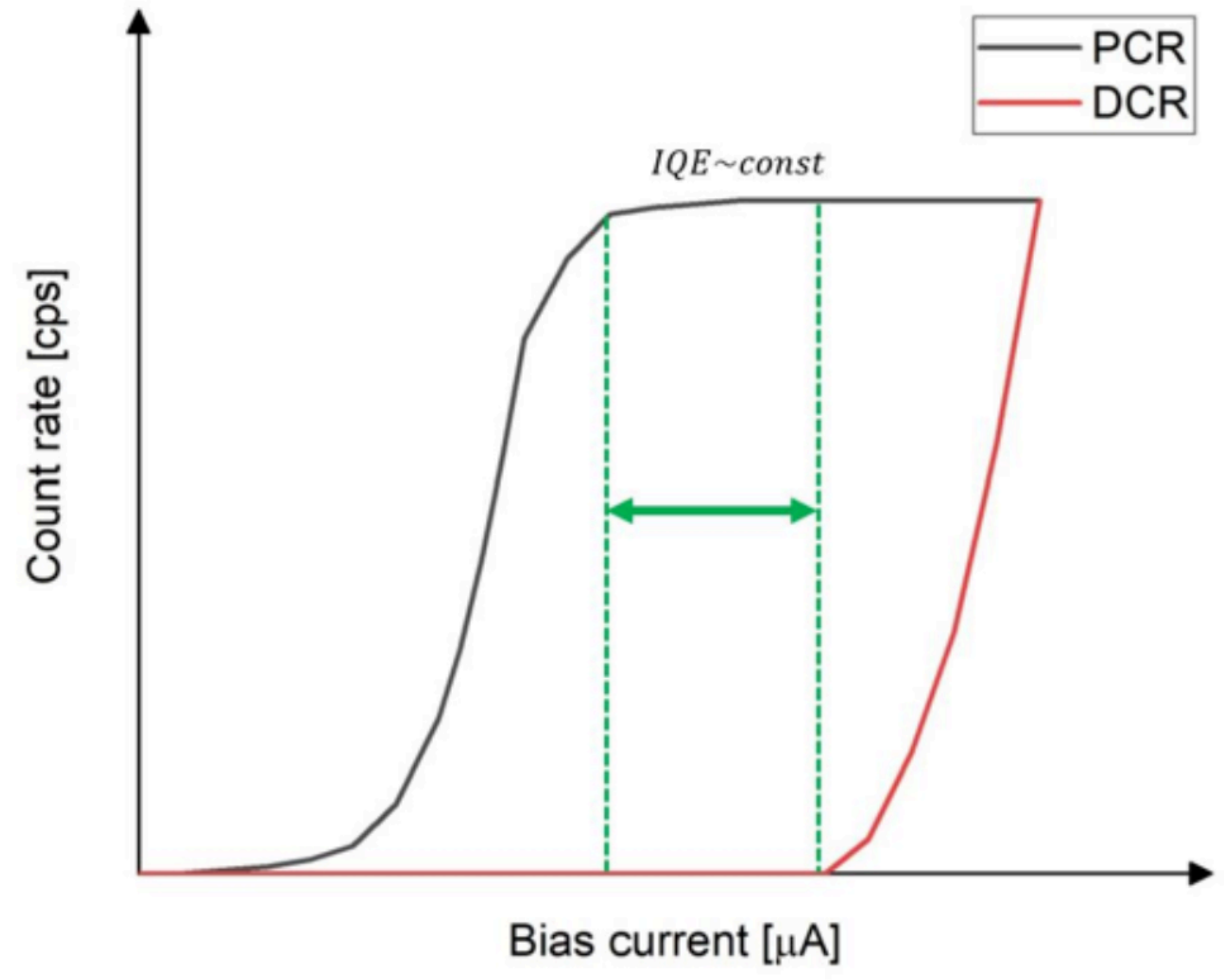
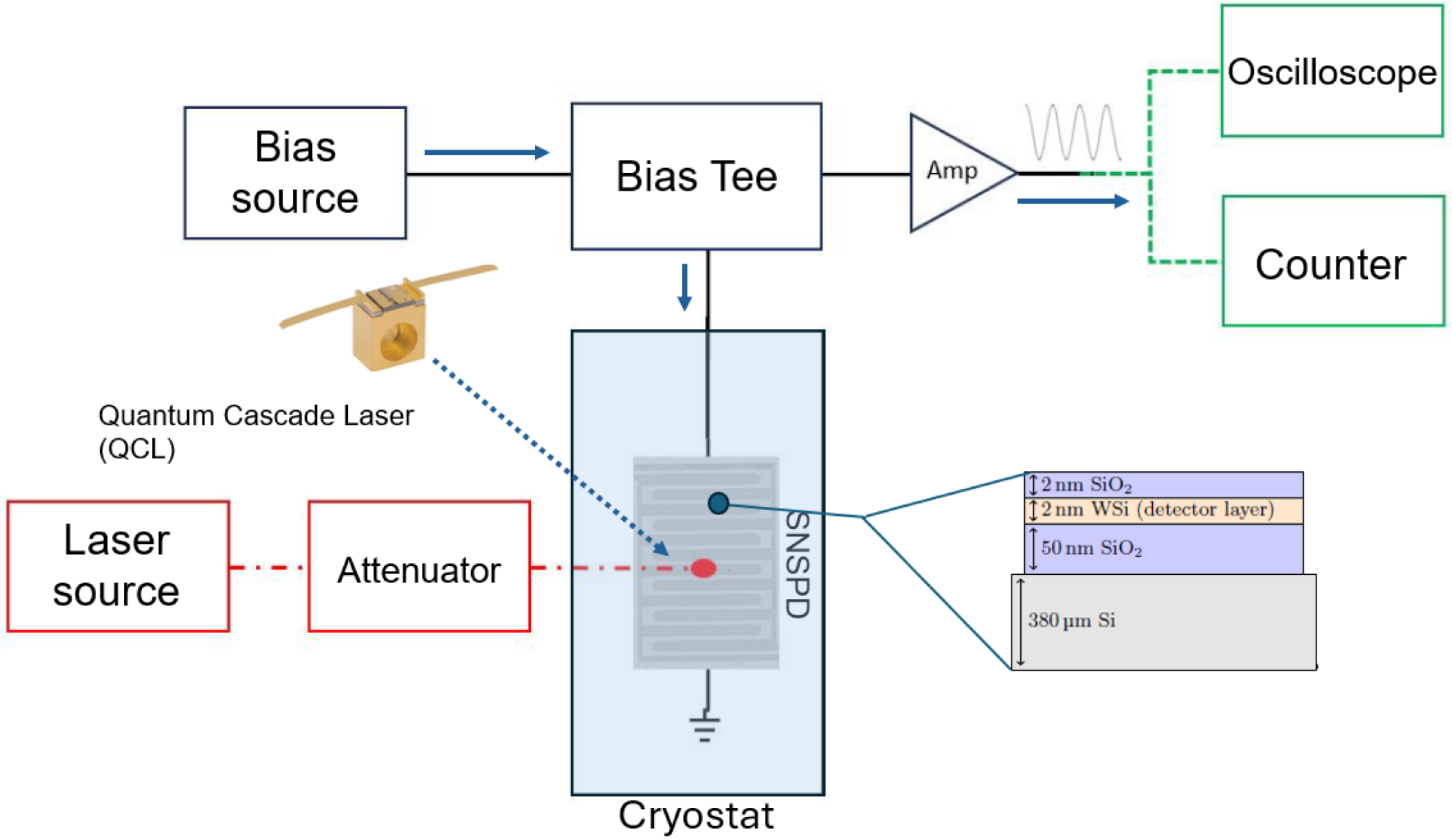
- Calibration in mid-infrared region with 5 µm and 11 µm lasers → corresponding to 0.25 eV and 0.11 eV
- Detection efficiency up to 98%
- Set working point at 12.2 µA and 100 mK




Bias source

Bias Tee

Amp

Oscilloscope

Counter

Quantum Cascade Laser (QCL)

Laser source

Attenuator

SNSPD

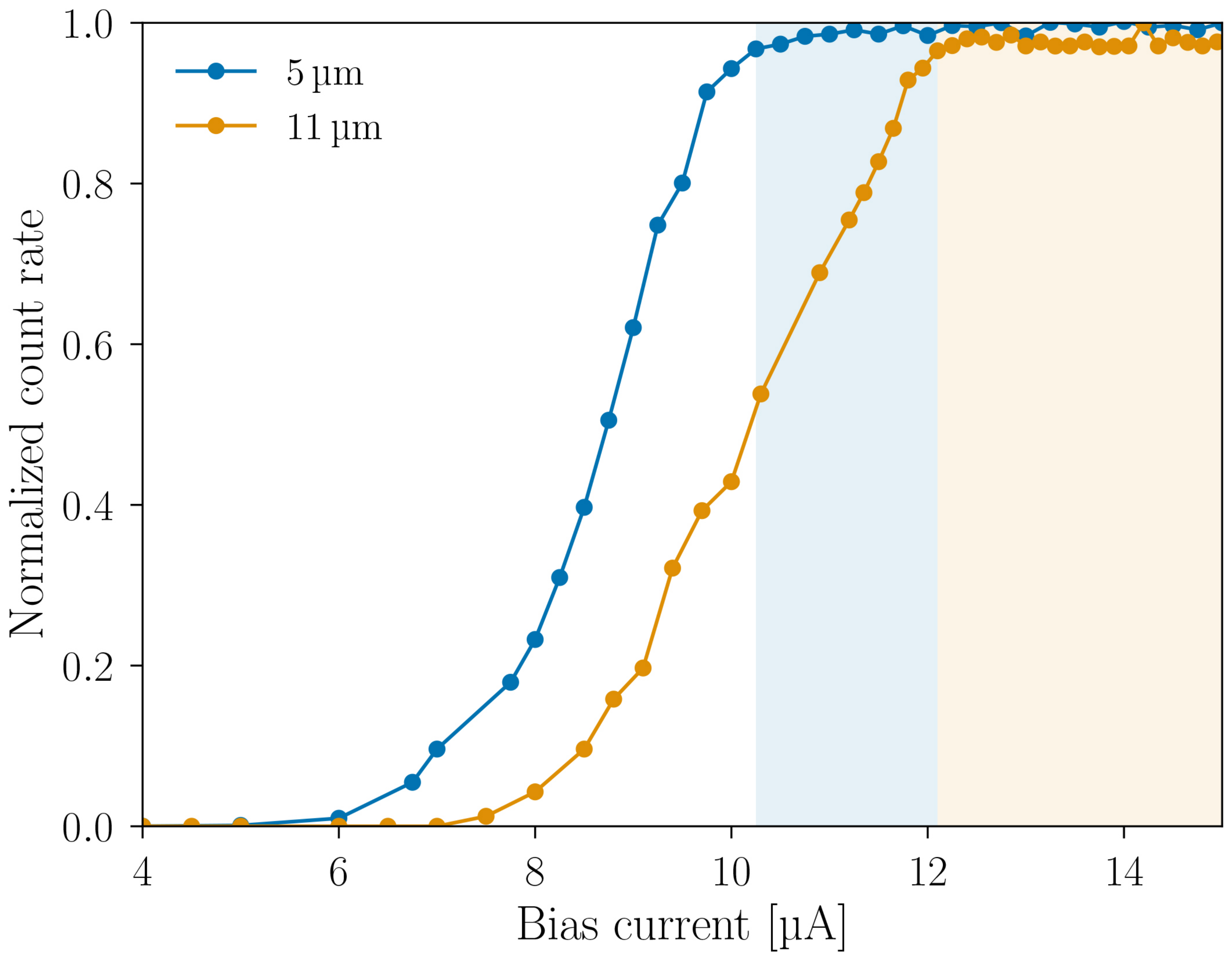
Cryostat

2 nm SiO$_2$

2 nm WSi (detector layer)

50 nm SiO$_2$

380 µm Si



Data taking

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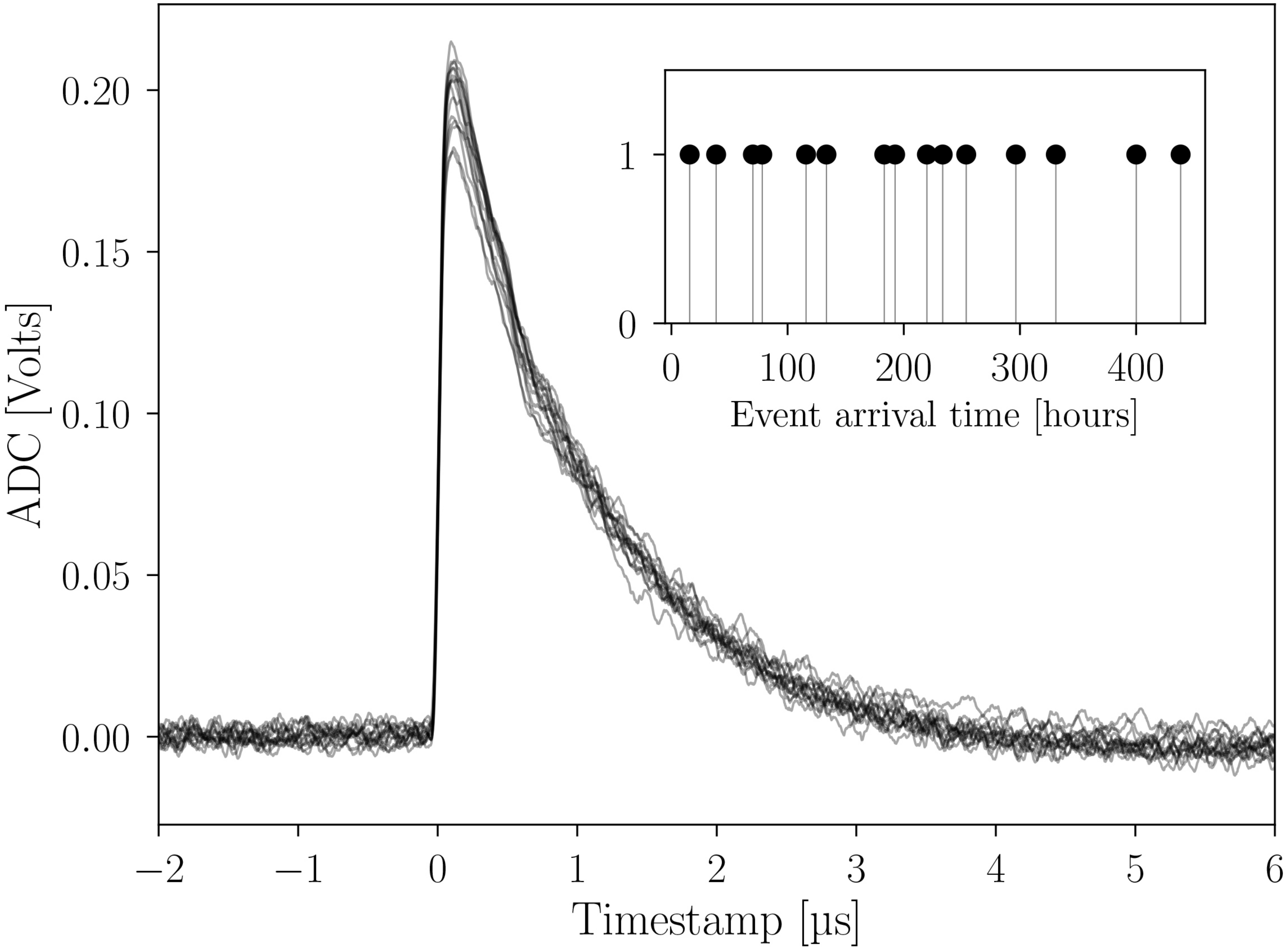

- Livetime: 415.15 hours
- 15 individual non periodic pulses = 10^{-5} Hz
- Pulse shape not energy correlated
- Not enough statistics to detect anisotropy in rate
- Constraints from total count rate
- 95% C.L. from Feldman-Cousins
- Projection for 10^7 pixels and threshold of 0.04 eV (29 μm)

Limit setting

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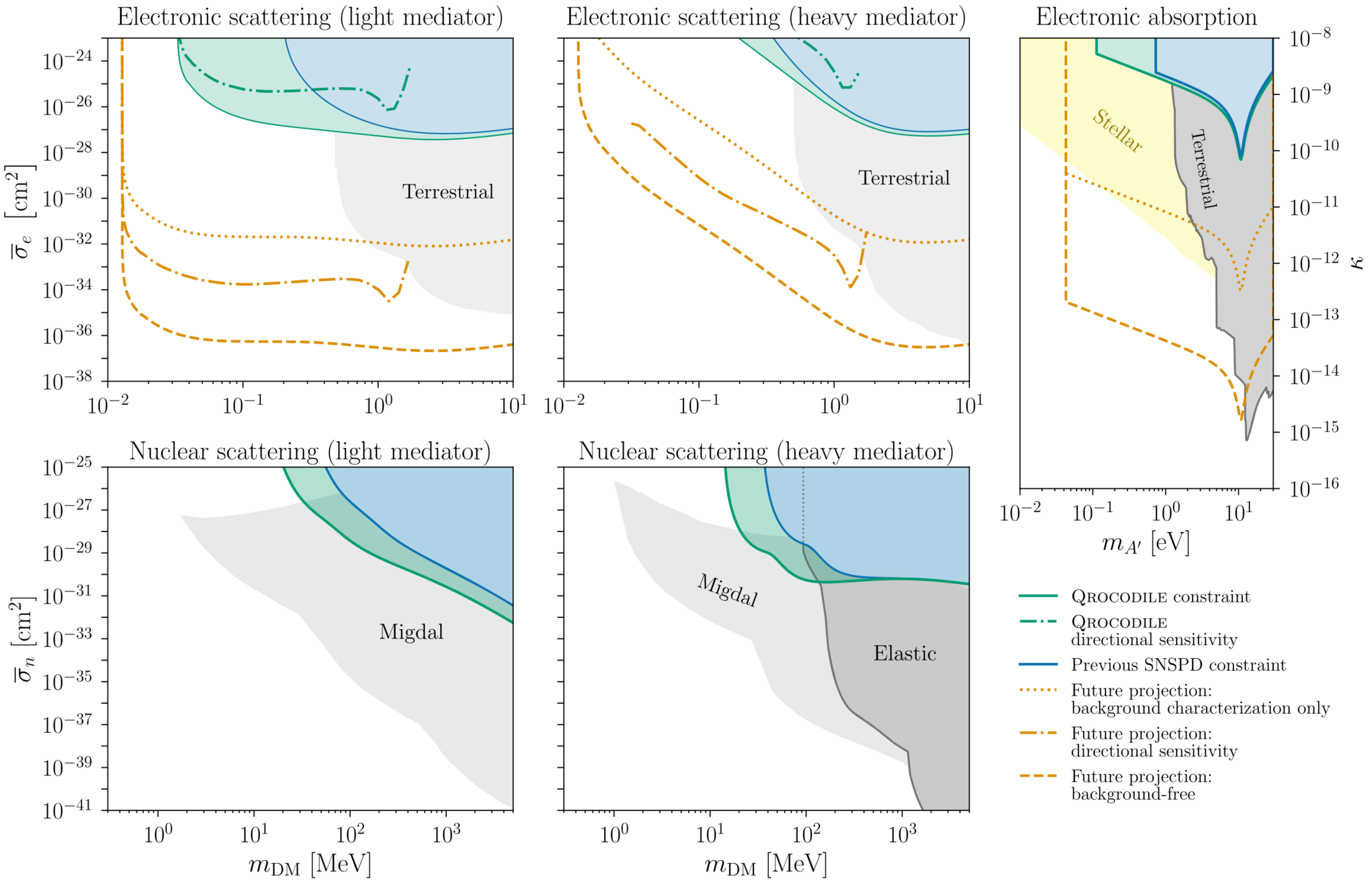
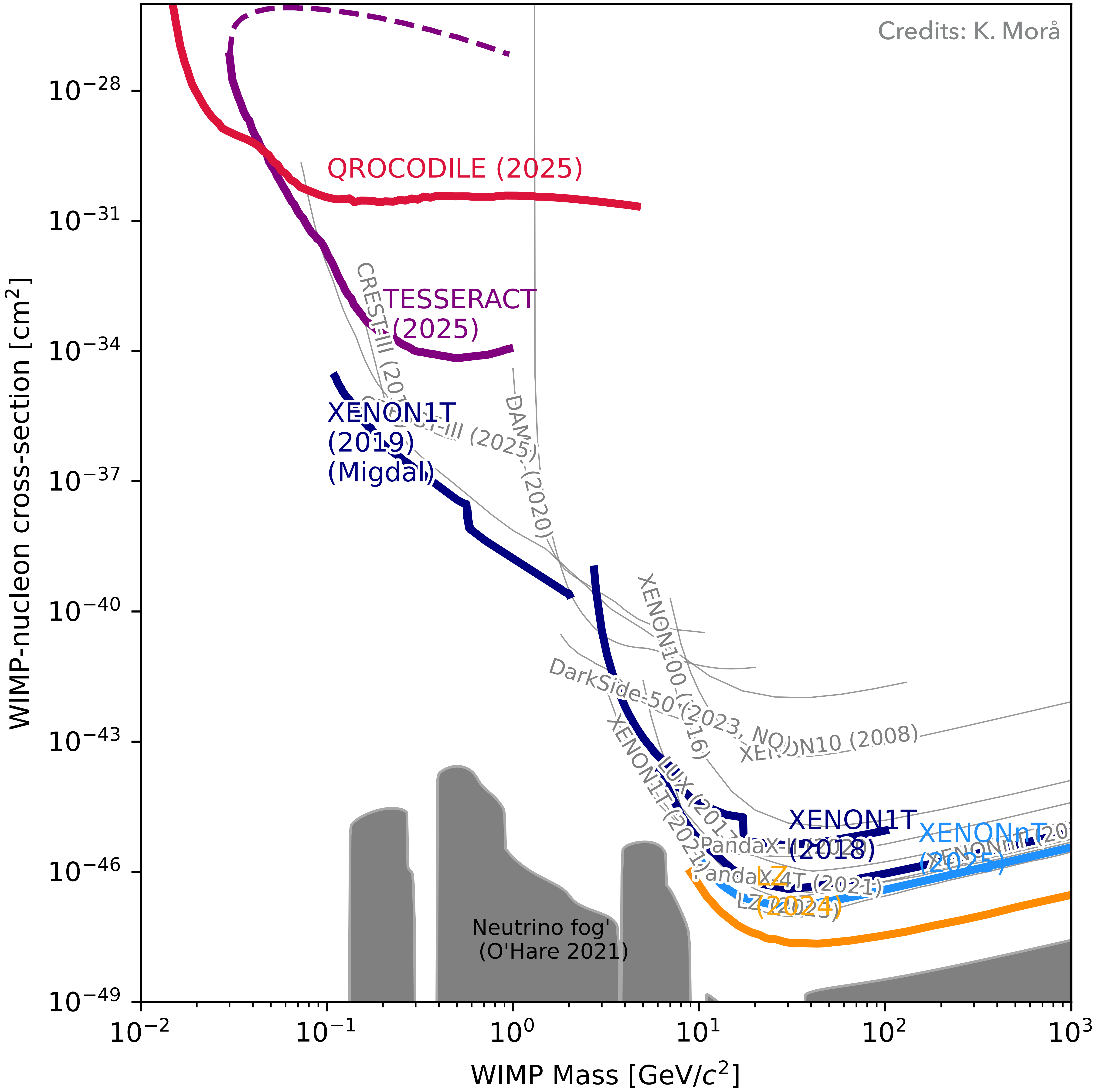


Current scenario



Next plans

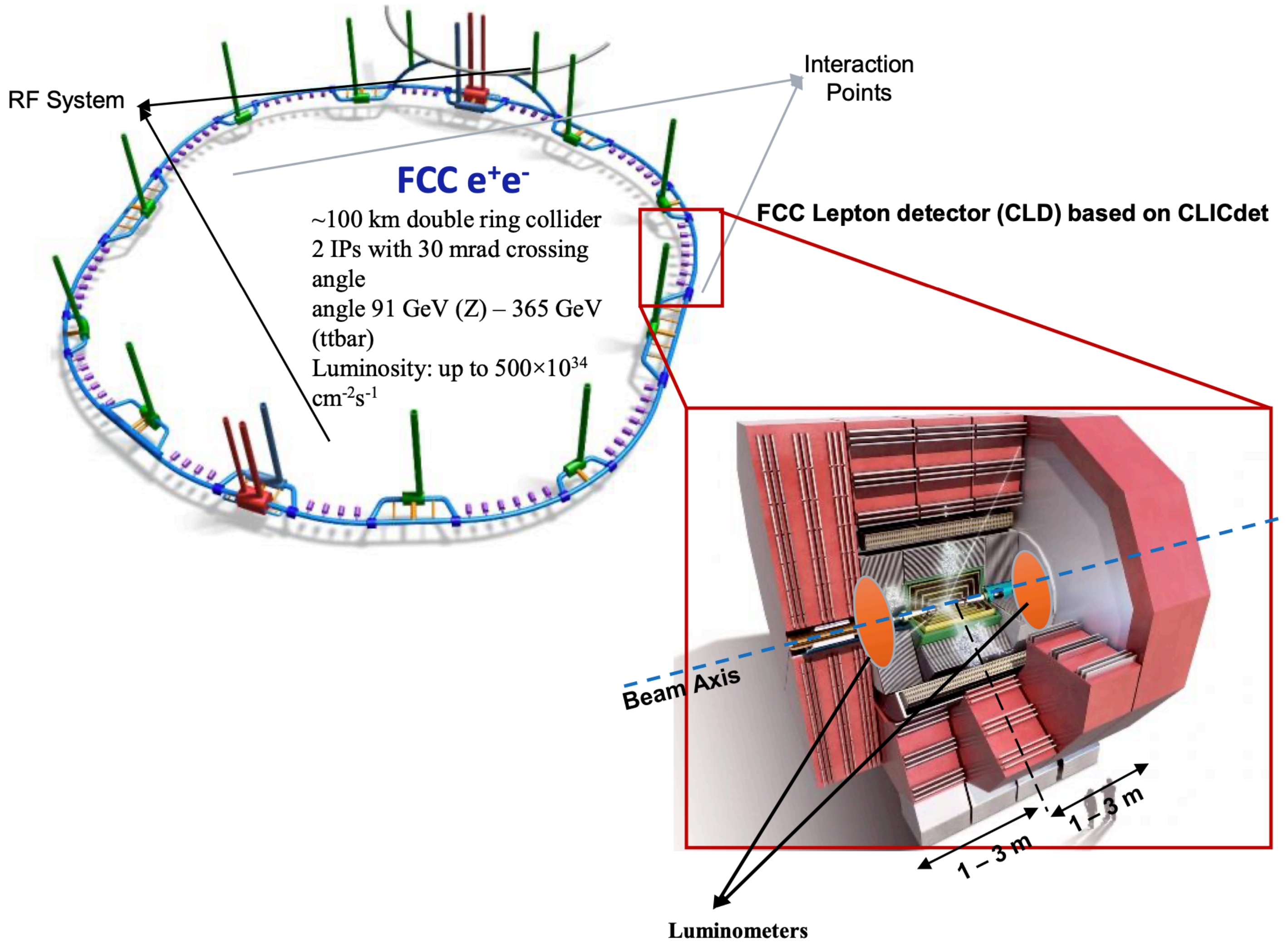
Temporary downtime during migration to alternative sensor suppliers

New sensors production:

- Moving UZH production to EPFL facility
- WSi chip from JPL - 1x1 mm with 8 pixels
  - Already fabricated, in Geneva for encasing
- Uni Geneva joining - production of MoN films, 800x800 um with 4 pixels
  - Validation of the production line
- Collaboration with DRD5 and the UZH CMS group (development for FCC)

Detector active area

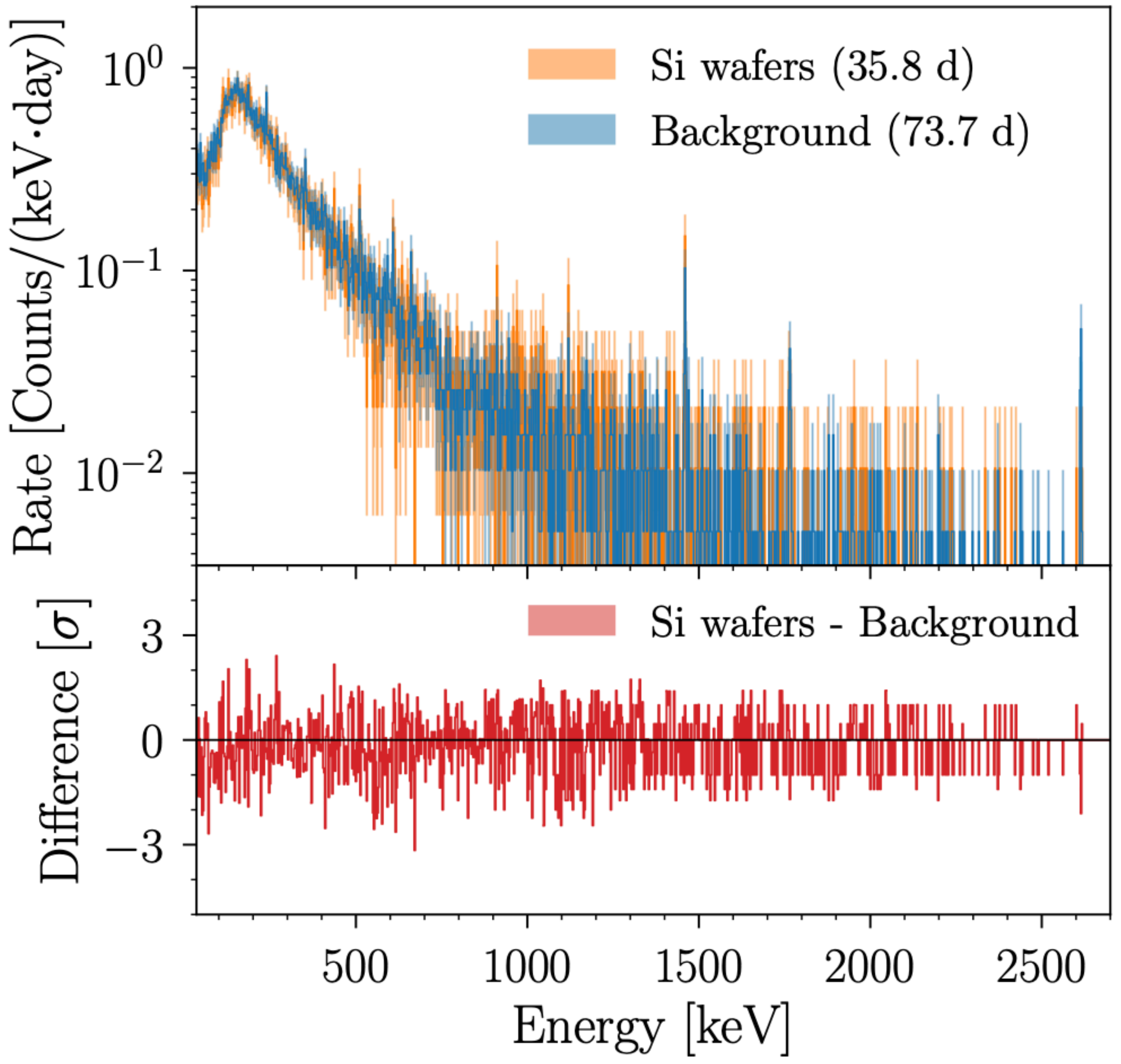
JPL sensor

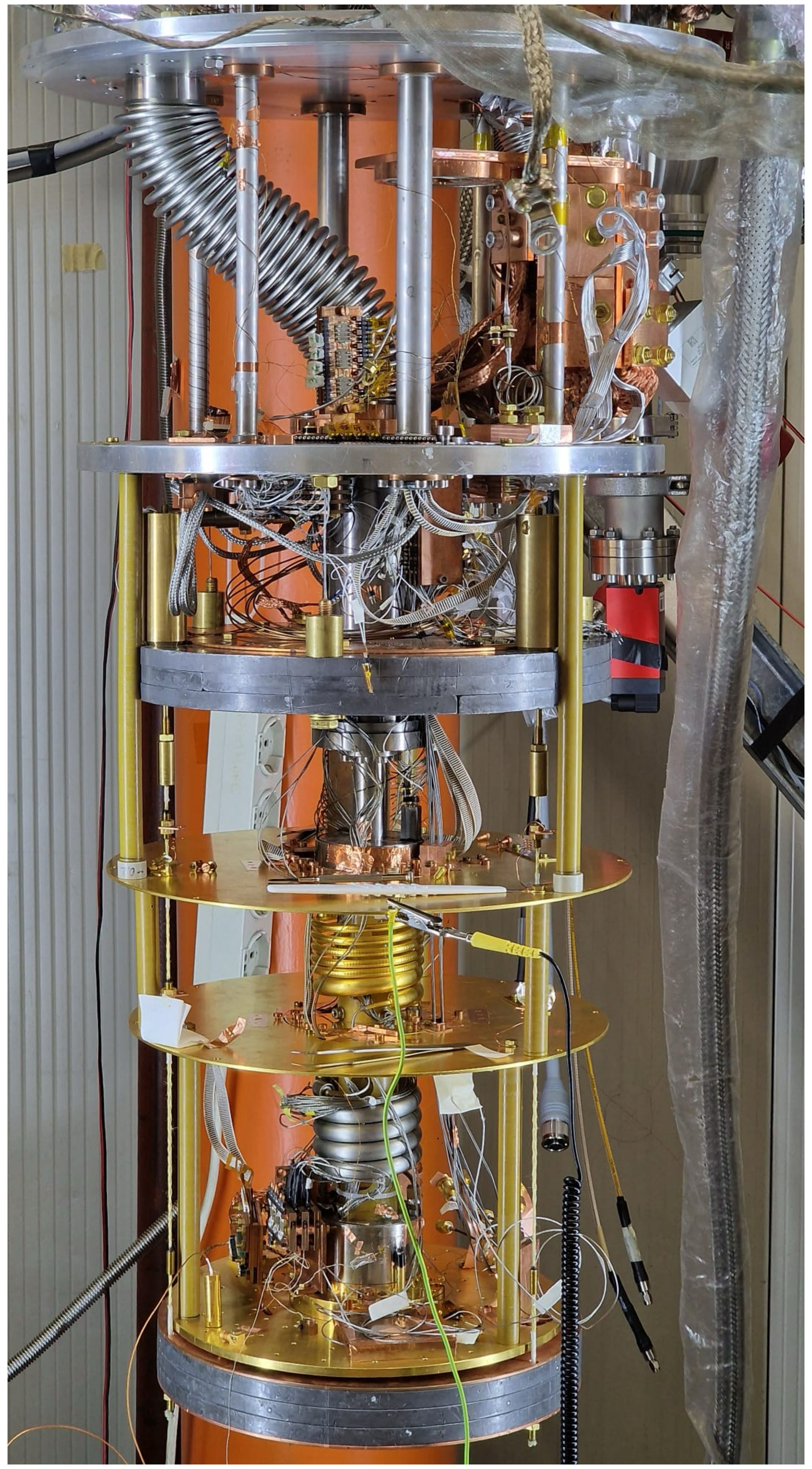


QROCODILE underground

Origin of the events?

1. Measurement in underground lab to disentangle background contribution from cosmic rays
   - IETI facility at LNGS in Italy
   - Test runs to setup readout and electronics
2. Material radioessay for contaminant tracing
3. MonteCarlo simulations

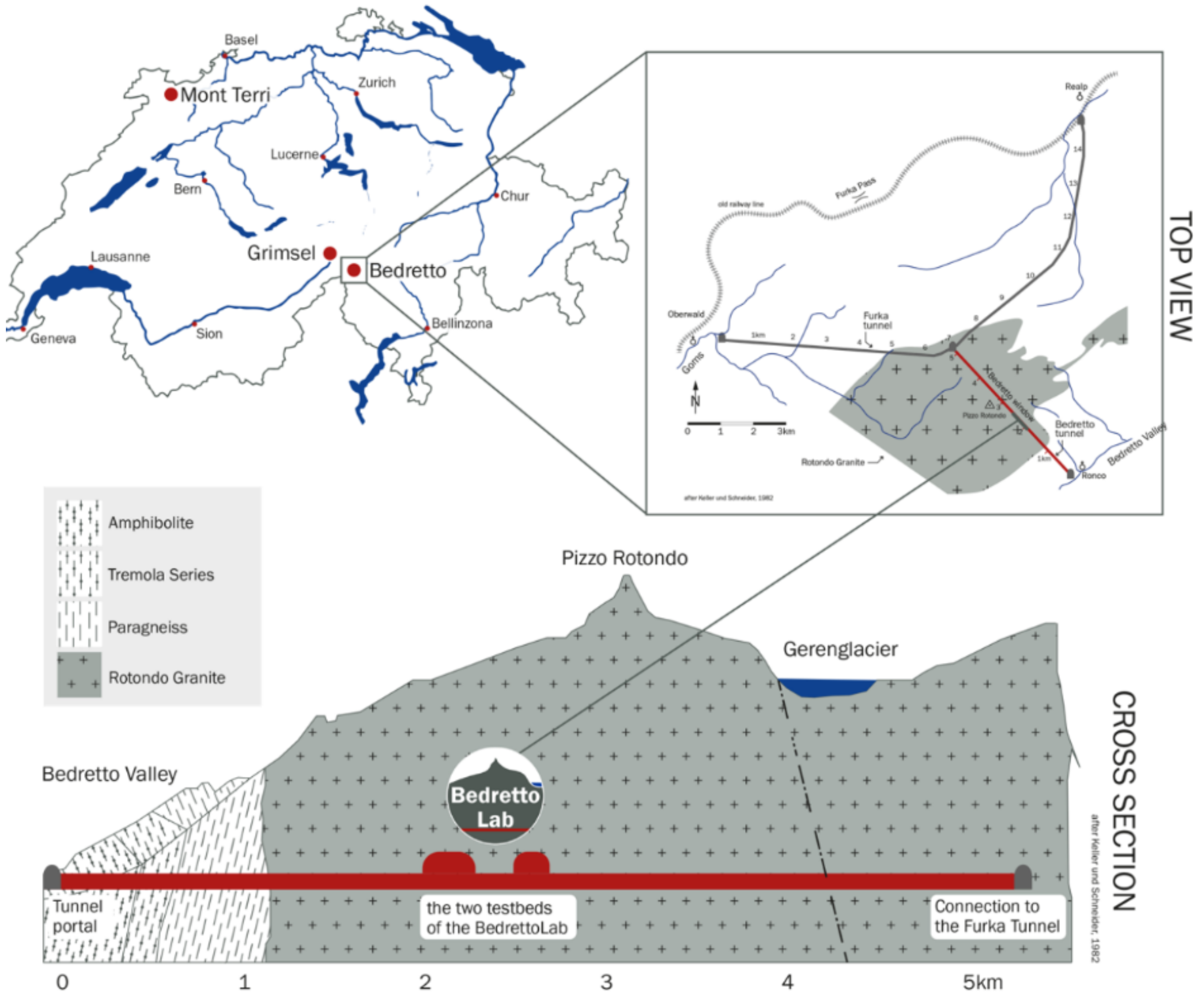




Bedretto Lab

arXiv: 2512.14815

- Underground tunnel in Switzerland - 5.2 km in side access of Furka train tunnel
- ~1000-1500 m deep, three caverns 6 m wide and 50-100 m long
- Since 2019 used by geophysics groups at ETH - since 2025 particle physics involved

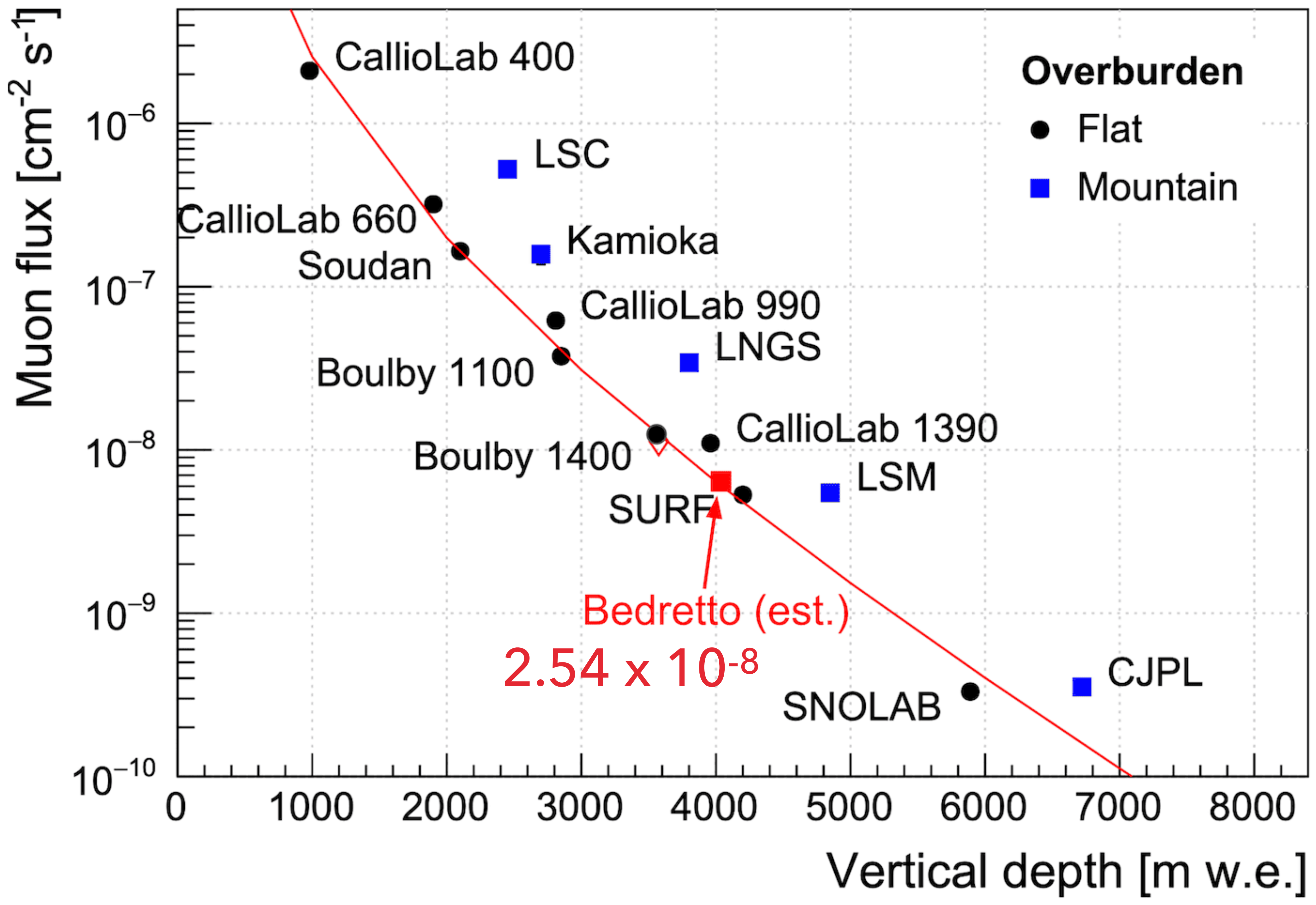


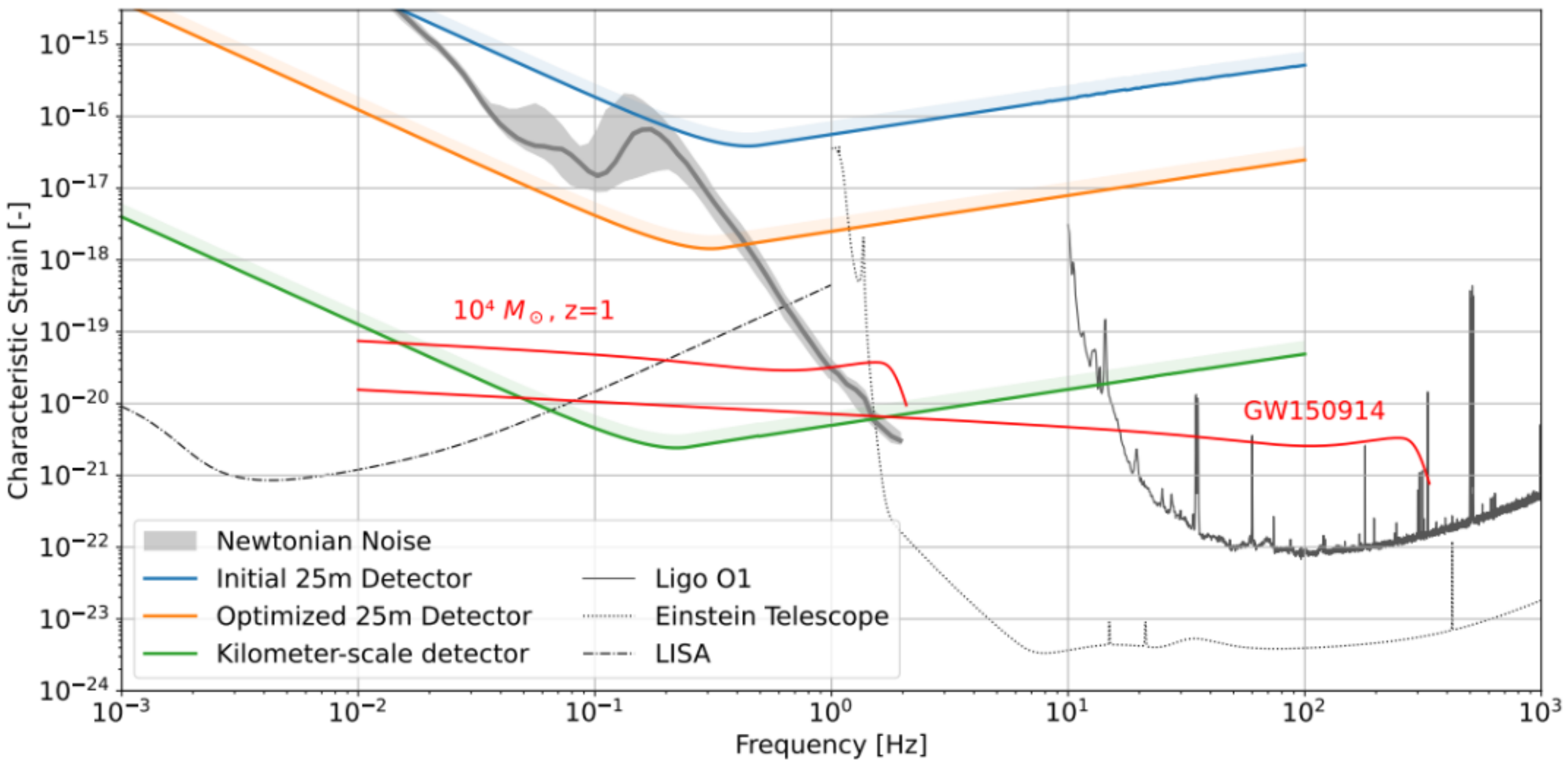
BEDRETTO LAB
UNDERGROUND PHYSICS

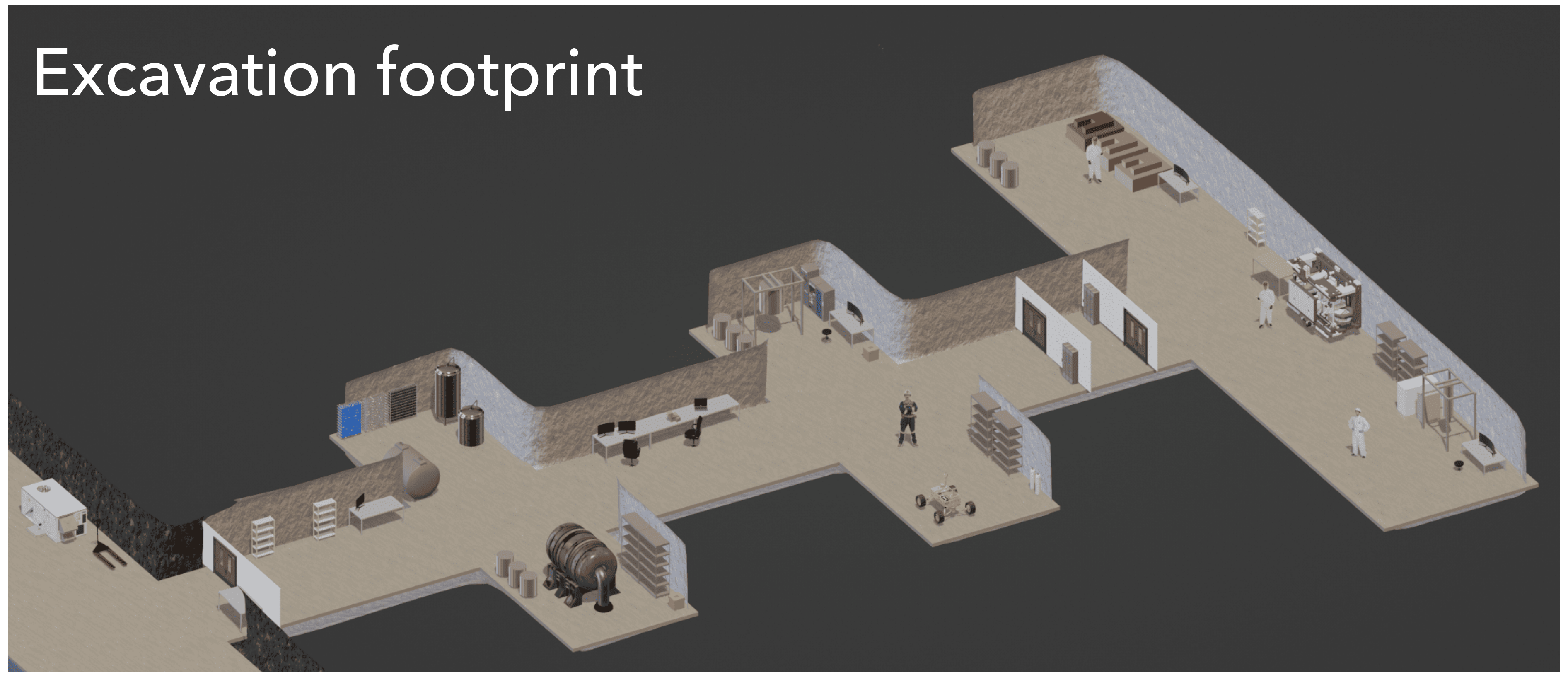
Bedretto Lab

- Radioactivity background characterisation campaign
- Mid-size astroparticle experiments in ~2 years
  - Dilution cryostat for SNSPDs and quantum sensors
  - Gravitational waves interferometer
  - Small scale TPC for R&D, HPGe low background counter,…

arXiv: 2512.14815

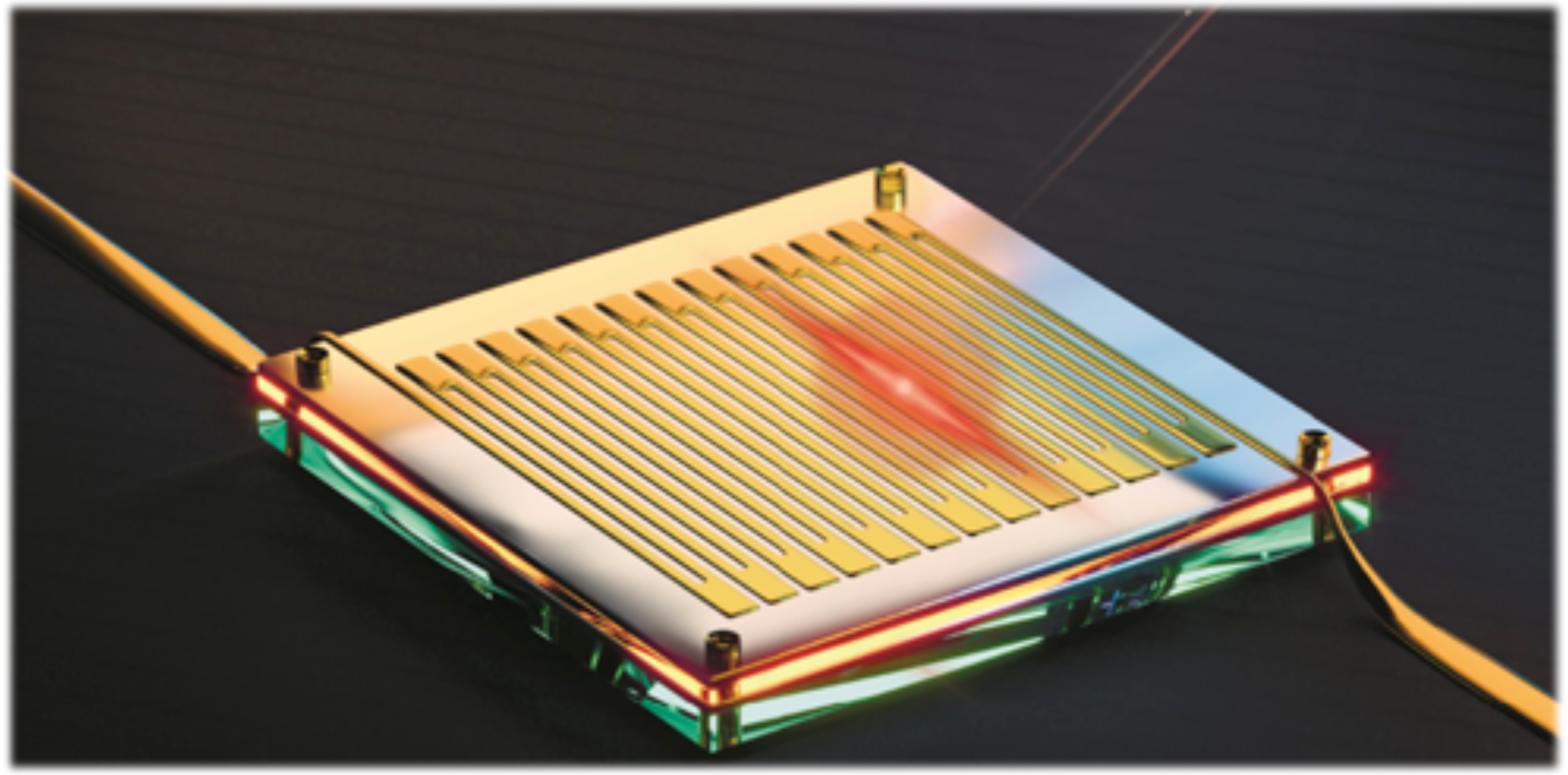






Conclusion and outlook

- Large area SNSPDs promising technology for low mass dark matter search
  - Simple readout
  - Easily scalable to larger masses
- First large area chip in aboveground measurement probed new parameter space
- Planned underground measurement
- Producing new sensors to optimise design and threshold



Crocodile

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Thank you!